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INSTRUMENTS

THE MAGAZINE OF MEASUREMENT AND CONTROL

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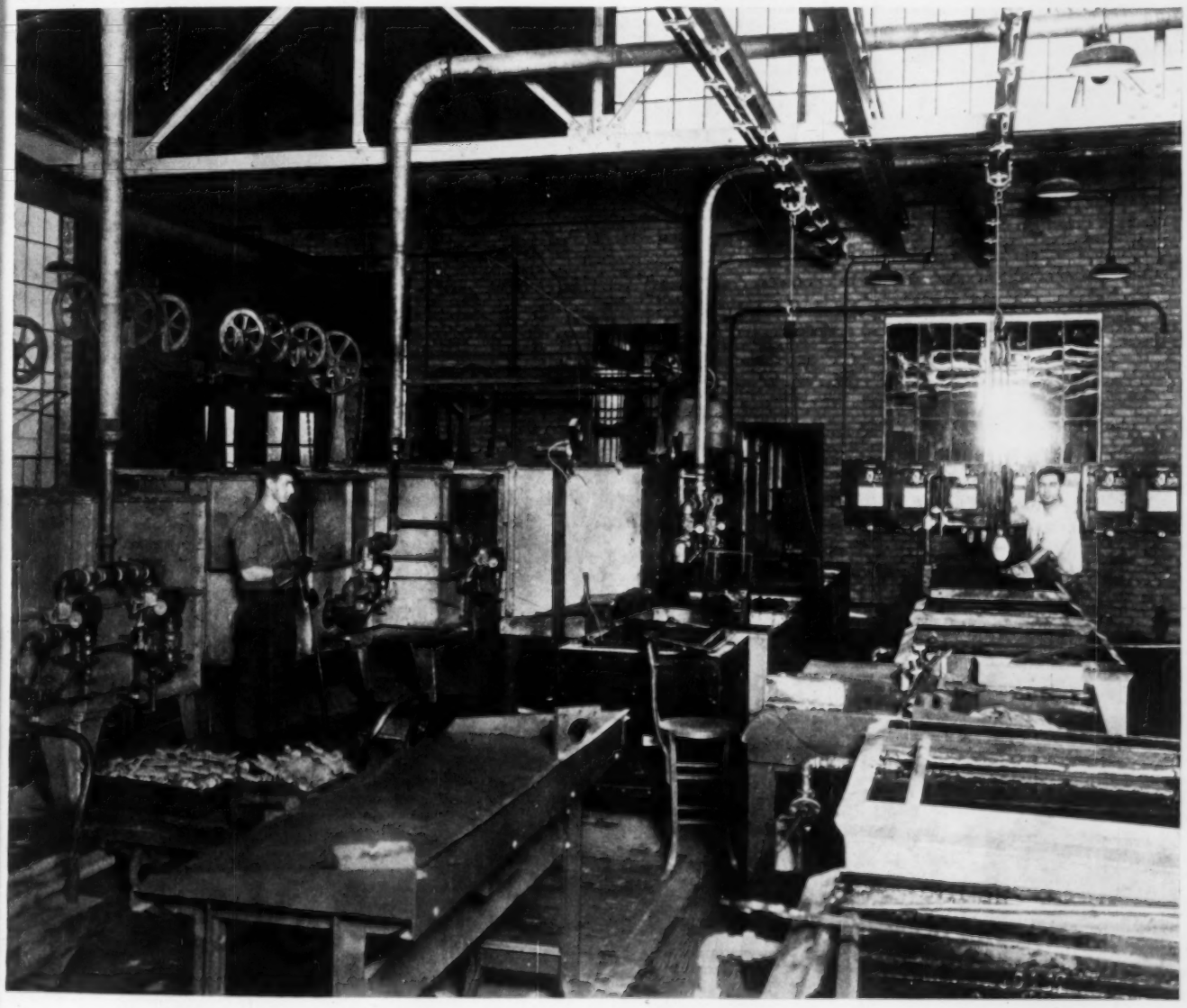

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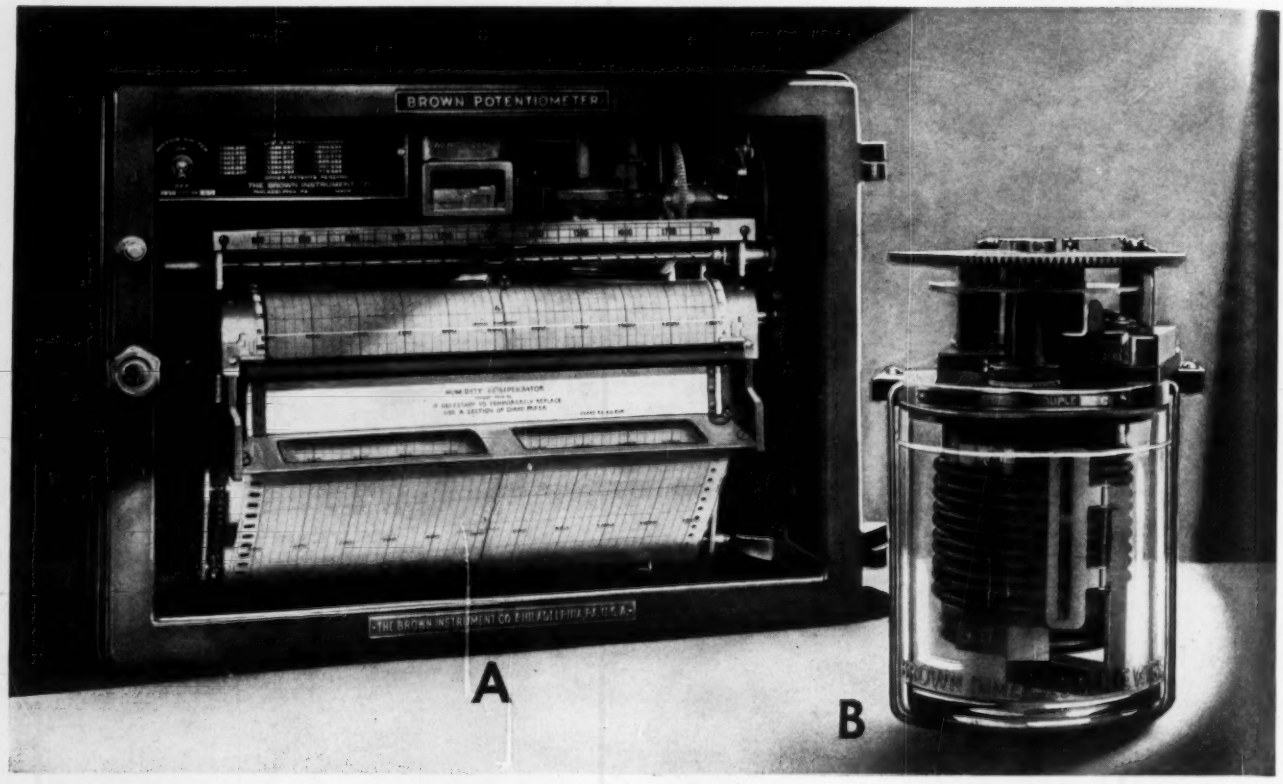

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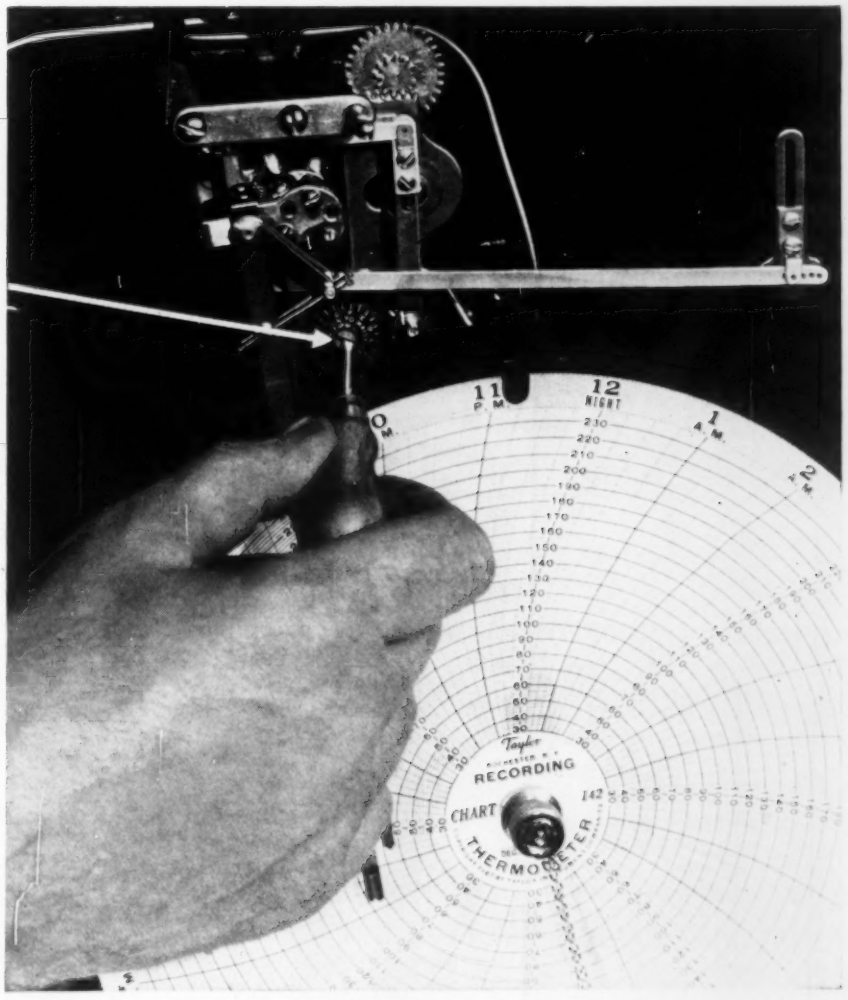
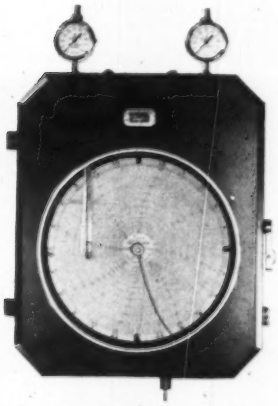


New Precision and Adaptability. The turn of a screw driver in this graduated dial "Universal Sensitivity Adjuster" gives you steady throttling, on-and-off action—any character of control desired. Its full range covers *extremely high* (A . . . B . . . C . . . D) to *very low* (I . . . J . . . K . . . L) sensitivity values.



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- Full length flexible pen arm gives more uniform pressure between chart and pen—new type micrometer screw adjustment.
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More information about this new instrument can be had by writing Taylor Instrument Companies, Rochester, N.Y., or Toronto, Canada.

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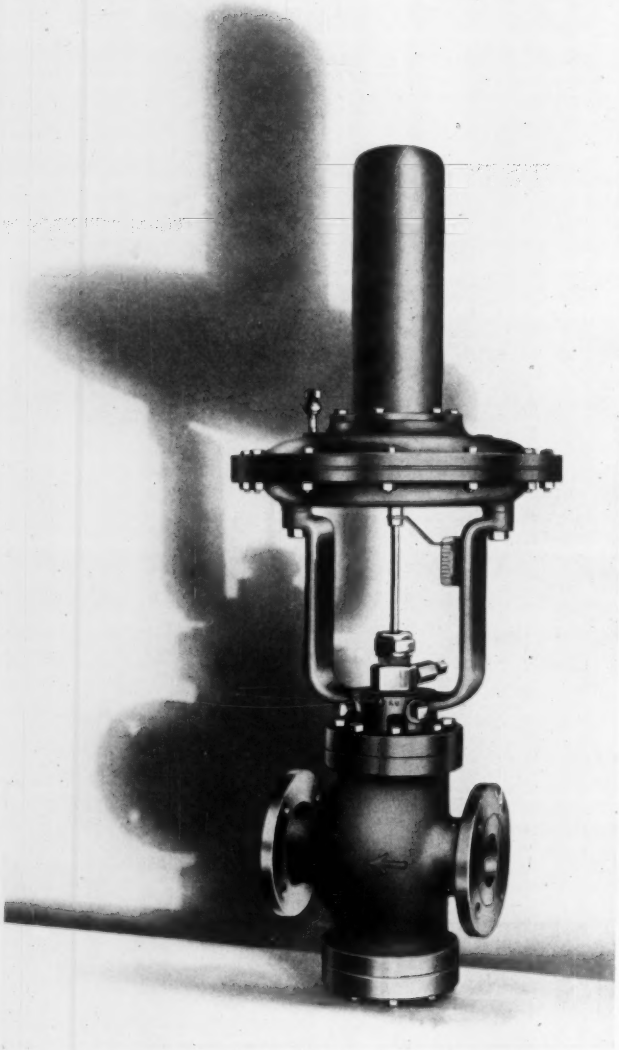

This unique valve corrects the common faults of Controlled Valves of the standard types.

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EDITORIAL COMMENT

In This Issue

◆ Although the application of automatic control to **Metallurgical Furnaces** is of prime importance, it has seldom if ever been the subject of an analysis both comprehensive and unified. **H. J. Velten's** article is just this kind of analysis.

◆ Requests for additional copies of our January issue containing **Professor Beitler's article on orifice coefficients** broke the record. An interesting supplement now appears in the form of a discussion of several values published in the original article.

◆ This month's installment of the series on **Electrical Measurement and Control** takes up the various types of electrical measuring elements—the "innards" of instruments as dissected by **Perry Borden**.

◆ In connection with one of the **New Instruments** last month we ran in this column a picture of its designer, Ben Smith, showing it to "the Grand Old Man of electrical instrument makers" which caused Paul MacGahan to write us: "There are at least three things wrong in those three

words. I am not grand, nor is 59 old. As to the man part—why not 'come up and see me some time'?" . . . So, in showing the men who developed the new GE ultra-violet meter (page 51) we'll not use adjectives: at the left, A. H. Taylor; at the right, Dr. M. Luckiesh. They—well, never mind!

The Front Cover

◆ This month's cover photo came from Minneapolis shortly before this month's leading article came from Chicago. From left to right there are four Bellevue Co. furnaces and two Strong, Carlisle & Hammond furnaces, all six equipped with Minneapolis-Honeywell motorized dual oil-and-air valves commanded by Leeds & Northrup potentiometers. The two quenching baths are equipped with Bristol contact type temperature controllers and motorized valves. The plant is that of the Commercial Heat Treating Co. in Detroit.

When Engineers Analyze Civilization

The Great God Waste. By John Hodgson. Published by the author, Eddington, England. 1933. Paper, 5½ x 8½ inches, 128 pages. Price, illustrated edition $2.00; cheaper edition $1.00.

The Irrepressible Conflict — Business vs. Finance. By D. C. Coyle. Published by the author, New York City. 1933. Paper, 5½ x 8½ inches, 16 pages. Price 25 cents.

SINCE 1930, most engineers find economics not the dry subject taught in colleges before the First World War but fascinating and related to our daily work and to our pay checks. (Whence part of the fascination.) Technical journals therefore have lately "gone economic." We may cite two friends: Ken Reid for his editorials in *Pencil Points*, and G. A. Stetson for both his own editorials and the many important economic articles he has run in *Mechanical Engineering*. Such writings by technicians are not wholly new: Towne read "The Engineer as an Economist" before the A.S.M.E. more than fifty years ago, when President Thurston likewise dealt ably with economics; Kimball, Flanders, Veblen, Ennis and other American engineers had not waited for the crash of '29. Soddy in England has become so famous as an economist that people forget that he is an engineer. (Which is the opposite of the case of an eminent financier-politician who, because of his early training, was boosted as The Great Engineer!)

—Hodgson has invented noteworthy fluid meters and combustion control systems. He has explored the world's capitals and jungles; he possesses a broad culture and a palatial Bedfordshire mansion. Dr. Coyle is a "typical" American engineer (C.E.) who holds an important NRA job and who speaks even better than he writes. He and Hodgson write better than do most non-technical economists. Judge for yourself:

[HODGSON]

. . . Some 50 men by the use of automatic appliances load 5,000 tons of lead ore a day—one-eighth of the world's total output. . .

I am haunted by a wan army of 20,000 unemployed from whom my efficiencies have filched away their life purpose and their means of adequate livelihood. It is the job of the efficient engineer to create unemployment. It has now equally become his job to join up with the other creative and executive members of the community in order to ensure that the people shall enjoy and profit by the unemployment which he and they provide. . .

We may define Communal Waste as human effort spent without adequate satisfaction to the individual or benefit to the community . . . . . We erect far too many factories and plants. We scrap serviceable plants. Vast sums are spent in advertising useless and objectionable articles, and in "high-power" salesmanship. (In industrial societies, such as our own, where purchasing power is deliberately limited, "salesmanship" and advertisement can only divert production from one industry or factory to another. They can never increase its total.) The savings of the thrifty are squandered and annexed by financiers and their satellites . . . Great losses due to strikes, lockouts and lack of zeal on the part of the workers. We sabotage so-called surplus products, and deliberately restrict production while the community's need remains unsatisfied. . .

It cannot be too strongly emphasized that in order to put things right economically, it is not necessary to "change human nature," but only to modify the system . . .

Credit Power—the right to grant or withhold the permission and encouragement to do and to use things—must be widely diffused . . .

The money system which is outlined below is put forward as an ideal rather than as the next step in practical politics. [Hodgson proposes abolishing gold-basis currency and issuing credits to the value of goods and services available in the "community"—which term does not necessarily denote a central planning body.]

As at present, the c r e d i t s issued would be exchanged by m e a n s of cheques . . . or token money for small purchases. . . There would be *no taxation* of individuals. . . *Nine months' endowed leisure*. . . Encourage and reward willing and able service. . . No upper limit of remuneration.

[COYLE]

. . . This is not a detailed plan for a new social order, but merely an essay in reorientation of thought.

An automatic factory, with all its expensive instruments, may be more productive than an old fashioned plant of equal cost and much larger size.

Apparently the power age is going to have comparatively little use for either labor or capital. Thrift and hard work, our ancestral virtues, are drugs on the market. The power age requires raw materials, power and technical brains, all of which we have in abundance. It requires markets, and there, for the moment, is where we are stuck.

[Quoting Justice Brandeis:] "Increasingly doubt is expressed whether it is economically wise, or morally right, that men should be permitted to add to the producting facilities of an industry which is already suffering from overcapacity. . . ."

Where shall we look for a means of keeping the balance between equipment and consumption, that will be not merely a plan for pumping the ocean across the boat? . . . The master plan of the economic system for a power age will necessarily be a plan for directing the flow of money. . . The traditional method . . . is by use of the tax system. . . The present problem is how to divert money from investment in commercial equipment to the consumption of the goods that business is trying to sell . . .

Consider the effect that would be produced by the establishment of a "ceiling" of personal income. Above this ceiling the supertax would take practically all the surplus income, except as the taxpayer could show that he had contributed it to some project of a non-commercial kind. Large sums which in good times would normally be reinvested in poison would be diverted to building art museums and hospitals and college libraries. . .

One of the most important products of the power age is leisure. Leisure *with* income.

Neither business nor the State dare tolerate reckless saving by those who have no need to save. . .

It is only beginning to be dimly recognized that in an age of plenty there is and must be between the interests of business and those of finance an irrepressible conflict. The normal processes of finance are poisonous to business. Finance causes instability."

Whether or not one agrees with these two engineers' diverse views, one finds both their little books illuminating.—M. F. Behar.

Automatic Control of Metallurgical Furnace Conditions

By H. J. VELTEN*

WITH respect to automatic control problems, there are two type examples of metallurgical furnaces: the open hearth steel melting furnace, and the furnace for heating semi-finished steel. In general, the conditions which are required to be controlled in the operation of these furnaces present more serious problems than those to be controlled in the operation of other furnaces.

Automatic control of the open hearth furnace has numerous aspects, including (a) control of supply or consumption of fuel, either at one definite rate, or at a rate which varies in accordance with the desired temperature, (b) regulation of furnace pressure, (c) control of shape, size and position of flame, (d) regulation of air supply in relation to fuel, so as to produce a definitely varying volume of products of combustion, (e) regulation of proportions of liquid and/or gaseous fuels, where two or more fuels are used in combination, (f) regulation of flow of exit gases so as to proportion distribution of heat between air and gas regenerators, (g) regulation of interval between reversals in accordance with indications of temperature or differential temperature between incoming and outgoing regenerators.

Control of a steel reheating furnace includes (a) regulation of temperature, (b) control of atmosphere within the furnace with respect to its content of combustible gases or oxygen, and (c) control of shape and position of the flame. It may also be desirable to regulate one or more of the conditions specified in the foregoing list pertaining to the open hearth. In that case, the means employed are generally the same as those to be described under the open hearth furnace.

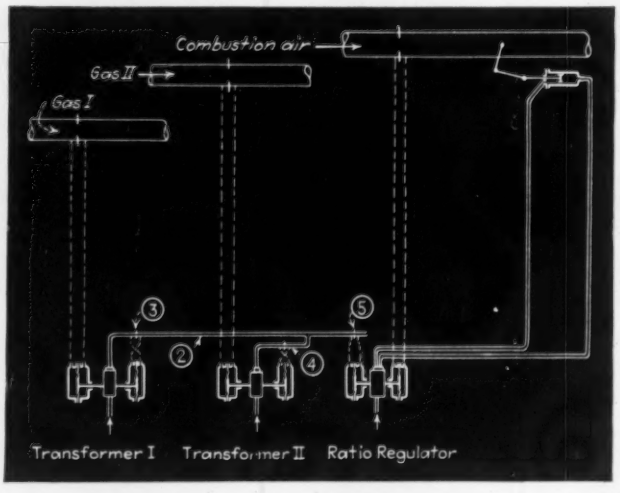

Fig. 1

ANALYSIS OF OPEN-HEARTH CONTROL PROBLEMS

Evidently, automatic regulation of furnace conditions should logically begin with fuel supply rate regulation in accordance with a *temperature* indication. Such regulation is technically difficult for two reasons; first, the lag between fuel regulation and resultant temperature, and second, the difficulty of identifying the desired furnace condition with a particular instrument indication of temperature. The first of these difficulties may be completely overcome; the second is now the subject of investigations and it is probable that a formula for analyzing furnace conditions on the basis of one *or more* temperature indications will soon be reduced to practical use.

Regulation of *furnace pressure* is in reality the control of flow of outgoing gases at a rate which corresponds exactly with their formation. This regulation, in order to be useful, should be as accurate as possible, since very small variations in pressure produce considerable changes in flow. Accurate regulation of furnace pressure prevents infiltration of cold air, and at the same time maintains a constant shape and size of flame, promoting continuous heat transfer and avoiding unnecessary wear on the furnace walls and ends.

Control of *shape and size of flame* is effected by the size and shape of the gas port, where gaseous fuels are used, and by the use of a regulated burner where all or part of the fuel is liquid: Such fuels are invariably atomized by steam, and automatic control of the oil-steam ratio in a correctly designed burner assembly permits regulation of the size, shape and position of the flame.

Regulation of the *air supply* is most simply and reliably effected by a regulation of ratio between fuel and combustion air. In the open hearth process, means must be provided for varying the ratio at successive stages of the process. This may be done manually, or automatically in accordance with the oxygen content of the products of combustion. Length and shape of flame requirements preclude the possibility of instantaneous combination of fuel and air. Gas and air ports are so shaped that the air meets the outside of a gas body, and the length and shape of flame, as well as its temperature, depend on other factors than the amount of excess air. Moreover, such excess has the bad effect of increasing the volume of products of combustion, increasing the carry-over of slag vapors to the regenerators, decreasing the efficiency of the latter, and for these and other reasons adding to the fuel requirement and increasing the cost of repairs.

Many open hearths are fired by a *mixture of fuels*. These may be: blast furnace gas and coke oven gas; coke oven gas and tar; coke oven gas and oil; blast furnace gas and oil; blast furnace gas, coke oven gas and liquid fuel or blast furnace gas; coke oven gas and producer gas. Other combinations of these fuels are possible and are used sometimes for the sake of efficiency and sometimes by reason of the availability of the fuels or one of them. Where combinations are used, the regulating system should be able to produce the following effects:

(a) Maintain a constant heat input to the furnace by automatically replacing one fuel by another in the event of a shortage of the first.

(b) Permit regulation, through one adjustment, of the total heat input.

(c) Summarize the air required for combustion of all the fuels and regulate a single air fan so as to provide the correct supply, maintaining the correctness of the air supply in case of variation in the supply of any or all fuels.

Devices for the complete automatic control of fuel mixtures have been worked out and are available. Fig. 1 shows a simple solution of this problem, and is discussed below.

The *shape of gas and air ports* of the open hearth furnace is usually designed with reference to conditions during the inlet phase of the process. Invariably the tendency at the outgoing end is to put too much gas through the air checkers. This may be avoided in some degree by varying the construction, but for complete adjustment it depends on regulation of dampers in the outlets of the two checker chambers. The instrument indications utilized for this purpose are those of comparative temperatures in the regenerator flues.

Automatic reversal is not automatic regulation in the sense in which it has been used in describing continuously maintained conditions. It is rather a determination of time for the reversing operation in accordance with an instrument indication of temperature or of differential temperature.

*Engineer, H. A. Brassert & Co., Chicago.

Substance of paper, "The Application of Automatic Control to Metallurgical Furnaces," presented at annual meeting of American Society of Mechanical Engineers, Dec. 4-8, 1933.

HEAT TREATING FURNACE ATMOSPHERE CONTROL

The steel heating furnace varies from the open hearth only in the details of the regulation problems presented and also in the desirability of maintaining an *atmosphere* in which scaling will be minimized. This atmosphere may be maintained by regulating the fuel-and-air ratio, and either *checked* by intermittent or continuous analyses, or controlled from an indication of the content of combustibles in the products of combustion. An oxygen or CO_2 indication may also be used for this purpose. The results of atmosphere control are among the most important in the entire field of automatic regulation.

DESCRIPTIONS OF SOME CONTROL SYSTEMS

Automatic control, as specified in the foregoing, is more than the regulation of a single condition. Indeed, it has reached the stage where it deals with maintenance of relative conditions in a somewhat complicated system. Details might be given at great length, but space limitations prevent an extensive discussion. I shall, however, go somewhat further into a few details of metallurgical furnace control problems.

Pressure Control. The basis of regulation is undoubtedly the control of furnace pressure. Some other factors, such as combustion control, depend upon an absolutely constant furnace pressure. At first glance, this seems to be a very simple application of any controlling device, but investigation shows that perfect furnace pressure control is difficult to achieve, and yet it has to be maintained within 0.005" water for the reasons stated.

The oldest well-known draft control device is the bell type self-operating regulator, which operates a butterfly valve in the flue or in a side inlet. A simple calculation shows that with a bell area of 5 ft.^{2}, for instance, a variation of the regulated pressure amounting to approx. 0.04" is required to produce an operating force of 1 lb. The pressure connection for these regulators is therefore made to the *flue*, where a high minus pressure is available. Consequently, the *furnace* pressure will vary considerably with the load. For this reason, the self-operating draft regulator has been replaced by those employing auxiliary power: electrical, hydraulic or pneumatic. The primary system then actuates only a control relay, and can be made sensitive to the slightest variation of the pressure in the furnace itself.

The primary systems most commonly used for this purpose are of the submerged bell and of the diaphragm types. The bell has the advantage that its full area is utilized. With the ordinary diaphragm, only about ⅓ of its free area is effective. To increase the effective area, diaphragms for such low pressures are made up with metal rings at the center. The advantage of the diaphragm is its small volume combined with a minimum of travel, so that with any impulse variation, practically no gas flow accompanies any pressure variation: merely a transmission of static pressure. This important feature contributes to stability of regulation.

A second and equally important factor is that the regulating speed be a function of the extent of departure from control point. In considering any installation of furnace pressure control, it must be determined whether the existing time lag between the operation of the controlling device and its effect measurable in the furnace is within the limits of intrinsic stability of the control system. If not, an outside stabilizer must be applied to counteract any pressure-effect variation transmitted to the control relays or to the motion of the controlling device. Such a stabilizer is always necessary when furnace pressure is controlled by operating a damper between the waste heat boiler of an open hearth furnace and the stack. For precise draft control, the stabilizer should not permit any permanent departure from the desired value, *i.e.*, it should reset the original adjustment of the regulator after any control motion.

Combustion Control. I only wish to show one metallurgical furnace example, namely, the regulation of combustion air supply for several fuels. Fig. 1 shows two different fuel gas lines and transformers* producing* an impulse* which represents the total demand for combustion air for both gases. This impulse is used as the primary one for the combustion regulator, the secondary impulse of which is the volume of combustion air supplied to the furnace. The transformers must be able to receive a constant flow of air and to give out a flow which varies with the primary impulse. Both gases are measured by means of orifices. The differential pressure in line 1 actuates the primary diaphragm of transformer I. The amount of air flowing into pipe 2 depends upon the position of the transforming device, which in turn is set by the gas flow impulse. A small orifice 3 measures the amount of air going through pipe 2 and the differential pressure across this small orifice actuates the secondary diaphragm of the transformer. Therefore, any variation in gas flow will change the setting of the transforming device until primary and secondary impulses are in equilibrium. In other words, the air flow through orifice 3 is proportional to the flow of gas I. In the same way, the air flow through orifice 4 is proportional to the flow of gas II. The total of both these air flows is measured by means of orifice 5 and this impulse on orifice 5 is the demand for combustion air for both fuels. It is taken as primary impulse to any combustion regulator which controls the supply of combustion air so as to maintain a constant ratio between the total volume of fuel and combustion air. Any additional gaseous or liquid fuel may be handled with this control arrangement.

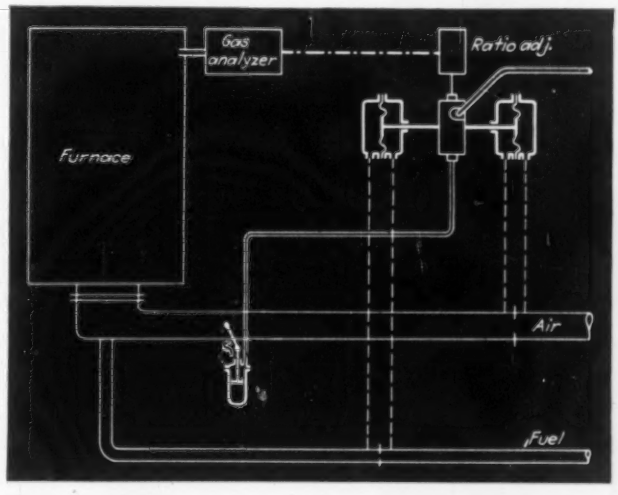

Fig. 2

An extension of this summarization principle makes it possible to maintain a constant heat input to the furnace, the regulating system automatically compensating for a shortage in one fuel by an increase in the other. In this application a gaseous fuel is regulated by a rate-of-flow controller. The flow of this gaseous fuel and of an auxiliary fuel, which may conveniently be liquid, are summarized and the impulse which corresponds to the combined flow is used to regulate the flow of liquid fuel. The liquid fuel will therefore be used in sufficient quantity to furnish the desired impulse of total heat input. This impulse may also be used as shown in Fig. 1 for the regulation of total combustion air.

Recent researches by Murphy, Jominy and Upthegrove in the United States and Schroeder in Germany have shown the extreme importance of control of furnace atmosphere in heating steel and the advantage in avoiding excess oxygen in the furnace atmosphere, particularly where the products of combustion consist largely of water vapor. A slight sacrifice of economy in the form of a few percent of unburned fuel may be much more than compensated by a saving in scale formed on the heating steel. Regulation of the furnace atmosphere may be accomplished by maintaining a definite ratio of fuel to combustion air. Such a system takes no account of variation in the composition of the fuel gas or leakage of the furnace system, and therefore is inaccurate with reference to the values of these variables. Regulation may also employ an impulse which varies with the composition of the atmosphere. The impulse may be electrical, resulting from the combustion of fuel gas contained in the flue gas or from combination of contained oxygen with fuel gas used as a reagent, or it may be one of specific gravity. The direct application of such an impulse to the regulating valve by means of a relay will not afford satisfactory regulation, because such an impulse is subject to considerable lag. The preferable method is volumetric control of air and gas, in a ratio determined by an impulse varying with the content of combustible, air or CO_2 as the case may be. Such a system, shown in Fig. 2 is accurate and stable.

Furnace Temperature Control. This other interesting control application on metallurgical furnaces is the first essential of "full automatic" furnace operation. Fig. 3 shows the arrange-

*From this point on, Mr. Velten refers to diagrams readily understandable by *Instruments* readers; and it no longer is deemed necessary to re-write entirely all sentences in which he uses the terminology peculiar to the engineering company with which he is associated. Technical readers will not find it difficult to follow Mr. Velten through the remainder of his valuable article.—Editor

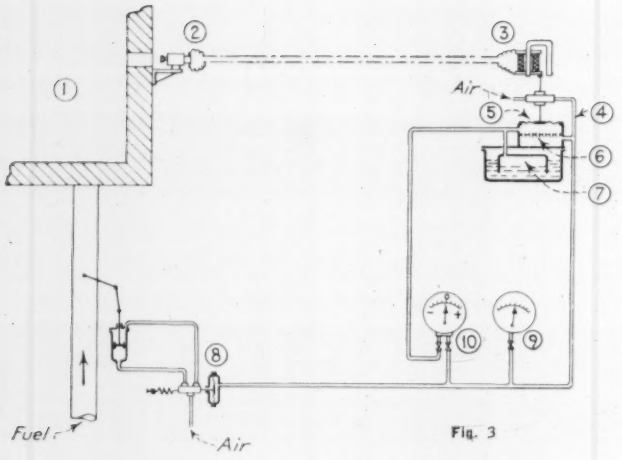

Fig. 3

ment of a temperature controller for this purpose. Extensive tests on the measurement of furnace temperatures are being conducted in different places and the optical pyrometer seems to be the most successful means of obtaining a reliable temperature impulse. In the diagram, 2 indicates such a pyrometer. The temperature impulse is transmitted to a metering system 3 which may be a potentiometer or any other system actuating a transforming device and being balanced by a counteracting air-operated diaphragm. The transforming device will always be in such a position that pressure resulting from the temperature impulse, and the air pressure in pipe 4 and on diaphragm 5, are in equilibrium. The air pressure in pipe 4 is therefore proportional to the temperature to be maintained and is transmitted to the pressure type regulator 8, which actuates a control valve in the fuel supply line to the furnace, so as to maintain a constant air pressure or a constant furnace temperature.

This would be sufficient for temperature control if it were not for the considerable lag, due to the heat capacity of the furnace. An analogy to this is the speed regulation of a turbine by means of the turbine governor, the turbine speed being here the temperature, and the inertia of the rotating masses being the heat capacity of the furnace. In both cases, the regulation must be stable. Mathematically it may be expressed as the equation of a harmonic motion:

$$m\frac{d^2x}{dt^2} + a\frac{dx}{dt} + bx = 0, \text{ with decreasing amplitudes.}$$

In this, x is the departure from the adjusted control point, and a the damping factor. This means that the regulator should not only be influenced by a departure but also by an impulse representing the speed of the departure. Practically, it can be accomplished in a simple manner by providing a resistance, for instance, a system of capillary tubing, between pipe 4 and diaphragm 5, and measuring the flow of air through this resistance. In order to create a measurable flow, the diaphragm chamber is increased by a submerged bell 7. An indicating gage 9, connected to the diaphragm chamber, will read the furnace temperature and its variations, while a differential gage 10, connected to both sides of the resistance, shows the speed of the temperature variations. Acting upon the regulator is the sum of both, corresponding to the equation

$$a\frac{dx}{dt} + bx = -m\frac{d^2x}{dt^2}$$

Stability can thus be achieved without making use of the potential energy or accumulating effect of the furnace, *i.e.*, without permanent variation in the regulated value. In special cases, the regulator may additionally be equipped with an isodrom, or single-point stabilizer, as mentioned under pressure control.

The regulator not only tends to maintain the adjusted temperature, but also to bring the speed of temperature variations immediately back to zero, so that a balance between heat input and heat consumption is always maintained. With a slight variation in temperature, it makes a rapid and considerable change in heat input, but only for a short time: until the speed of variation becomes zero. This is the same as what a careful operator would try to accomplish by regulating the fuel supply manually in accordance with an instantaneous indication of furnace temperature.

The temperature regulator may control either the gas or air supply, provided that a combustion controller is applied as previously shown. With especially favorable conditions and on small furnaces, the fuel and air valves may be interconnected. The conditions for successful application of this method include: constant pressure of fuel and air; both valves having the same characteristics; and the same resistance between valves and furnace. We seldom have these conditions, and a separate combustion regulator is therefore required in most cases.

CONCLUSION

Heretofore, automatic regulation has in many cases been applied to a single condition, usually furnace pressure. Comparatively few installations have been made in which control of fuel use rate, of furnace atmosphere and of furnace pressure have been simultaneously effected. In some cases where ambitious schemes of regulation have been attempted, technical shortcomings in the control equipment have prevented full realization of the expected results. Now, adequate methods and equipment are available for regulating the conditions listed at the beginning of this article. Accurate determination of the savings effected is difficult, since no metallurgical operation is completely stable with respect to conditions other than those regulated. Careful tests indicate a saving in fuel in excess of 10% in the open hearth furnace, with resultant advantages of higher production, lessened repairs and closer compliance with specifications as to composition and quality of product.

LETTERS to the EDITOR

Discussion of S. R. Beitler's "Discharge Coefficients of Sharp-edge Orifices"

To the Editor:

Thank you for the copy of Prof. Beitler's paper which I have studied with much interest. I have great respect for the accuracy of Prof. Beitler's tests and think it desirable that his data should be widely used. Fig. 4 contains all the essential experimental results for vena contracta taps on flow of water in pipe sizes from 1" to 14". It is very concentrated information and it seems likely that most meter users would prefer to have it shown by curves similar to those of Fig. 5.

Presumably everyone knows the formulæ for liquid flow but when you come to compressible fluids there are several possible coefficients and it is necessary to be more specific. In studying Fig. 5, several questions came up on which I think it might be desirable to have Prof. Beitler's further comments. In trying to transpose from Fig. 4 to Fig. 5, on several points checked, the coefficient values of Fig. 5 ran about 0.012 lower or about 2% relatively lower than Fig. 4. This may be due to the "correction for compressibility" mentioned in the title under Fig. 5. If that is the explanation, then the coefficient shown in Fig. 5 is what would be fully described as $C_1 Y$, that is, the hydraulic coefficient based on the upstream density and multiplied by the "expansion factor" Y. If so, what value of Y was used? With a head of 50" of water on air of atmospheric pressure, the head represents a drop of some 12% which calls for quite a substantial correction when the upstream coefficient C_1 is used, though the correction is small if the downstream coefficient C_2 is used.

I should like to see a sample calculation of the Reynolds number. I figure for a disk orifice of 1½" opening installed in a large size pipe, for air at one atmosphere, the Reynolds number is about 153,000 but there is a chance for argument on this.

The two lower values of coefficient at the left of Fig. 5 appear to be inconsistent with the other values. Which ones are right?

Does Fig. 6 show the coefficient for corner taps directly comparable with Fig. 5 for vena contracta taps? There is no note under Fig. 6 to indicate that it is corrected for compressibility and this raises a question whether they are on the same basis except as to the pressure tap location.

New Jersey Meter Co. — C. A. Dawley
Plainfield, N. J. — *Chief Engineer*
February 1, 1934

Author's Closure

To the Editor:

The questions which Mr. Dawley asks are very legitimate. In the attempt to present as many facts as possible in a minimum of words, certain things which are obvious to one who has lived with a subject for years were left out and these omissions may lead to questions from one not so familiar with the subject.

I think that Mr. Dawley has calculated the values of Reynolds number at the upstream pressure connection, which is the value used in European practice, while the Reynolds num-

(Continued on page 51)

Electrical Measuring Elements and Scales*

By PERRY A. BORDEN† and M. F. BEHAR**

1. Classes of Measuring Elements

(a) The Four Principles

Although the nature of electricity is not fully known, many of its manifestations are distinct and reproducible, and they obey definite laws which remove arbitrariness from the assignment of numerals. Therefore, these entities (such as "electromotive force") are true magnitudes and it follows that their orderly combinations with one another, with non-electrical fundamental magnitudes (such as "angle," "length" or "time") or with measurable properties of matter or space (such as "resistivity" or "permeability") are all magnitudes, hence truly measurable. In practice, the values of electrical magnitudes are determined by performing essentially simple measuring operations upon tangible, convenient and reproducible *effects* which they may produce. A voltage or electrical potential difference, for example, may be considered as an electrical pressure, and this pressure may be translated into a conveniently measurable mechanical thrust. Again, an electric current, though consisting of a migration of invisible and mysterious electrons or "negatrons" along a conductor, may cause heating, chemical or magnetic effects, and any of these may be made to produce mechanical forces capable of exact determination by mechanical means. We need not go into theories: the reader can satisfy himself, by consulting any standard text, that there are numerous such effects which are absolutely reliable. The number of different designs of measuring instruments thus made possible is enormous, but if we consider only the effects which are employed for quantitative determination of electrical values, we note that they fall into four groups:

(a) electrothermal
(b) electrochemical
(c) electromagnetic
(d) electrostatic

These four groups of utilizable effects give us four basic principles of electrical measurement, employed in all instruments that are strictly electrical, and in numerous other instruments as well. These four principles lead to a corresponding division of the essentials, namely the measuring elements, into four classes. An instrument may be complicated, and it may employ more than one principle, but a measuring element can only belong to one class and can only employ one of the four basic principles. Moreover, a measuring element is that which has but one measuring function. Before proceeding any further into the treatment of electrical instruments for various engineering purposes, therefore, it is necessary to take up their electrical essentials, sometimes known as "movements" but more precisely defined as measuring elements. In the following sections, the principal types of measuring elements will each be described briefly and non-mathematically. Some of them will be dealt with in great detail *as instruments* in later chapters; some will not be referred to again.

NOTES. (1) The division of the utilizable effects into four basic principles is firmly established: hence the division of measuring elements into four classes is logical. To discuss "movements" only would lead to complications. For example the "pointer" of a cathode-ray oscillograph is a beam of electrons.

(2) Our definition of a measuring element is believed to have other advantages. For example the cathode-ray oscillograph already cited seems at first glance to be an extremely complicated device. Its essential "movement" is its tube, but this tube may comprise two distinct measuring elements belonging to two different classes if its beam is deflected vertically by a static field and horizontally by a magnetic field. In this case the simple-looking "bottle" (which actually is a simple device) comprises nevertheless two elements: an electrostatic measuring element with a vertical scale and an electromagnetic measuring element with a horizontal scale.

*Third chapter (XXXI) of Part Seven (Handbook of Industrial Electrical Measurements and Control) of Béhar's *Manual of Instrumentation*. See editorial announcement of this series on page A7 of November 1933 *Instruments*. A complete chapter of this new handbook will be published in each issue of *Instruments* throughout 1934 and 1935. Each chapter is subjected to a final revision, and then set in type, shortly before its appearance in this serial form, in order to assure that the subject matter is thoroughly up-to-date. This new book is not published serially in any other periodical. Entire contents copyright. To be issued in book form on or about Jan. 1, 1936.

†Member A.I.E.E. **Editor, *Instruments*

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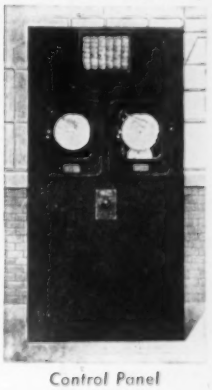

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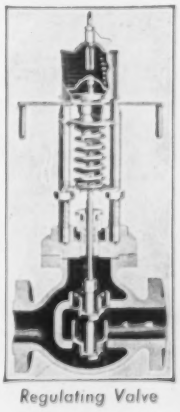

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(3) Although the following discussions are based on the measuring element scheme, the term "movement" is not excluded. On the contrary, it will be used whenever an instrument movement is discussed as such—that is to say, when its construction is of interest.

(b) Restoring or Control Forces

In order that the mechanical force derived from an electrical source in an instrument may be indicated or recorded as a scalar quantity it is usual to oppose the actuating force or torque by an equivalent restoring force or counter-torque whose value varies with the deflection of an indicating member. In many non-electrical instruments the position of the pointer is controlled by the interaction of a measuring torque and a restraining torque—both residing in a single part of the instrument, as a Bourdon tube or a bimetallic spring. In electrical measuring elements, on the other hand, the actuating torque and the

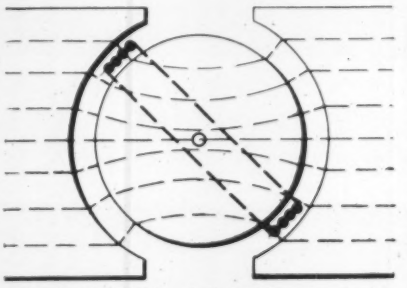


Fig. 31-1. Principle of the d'Arsonval measuring element. Because of soft iron core, path of rotation of moving coil (between pointer "stops") lies in a radial field.

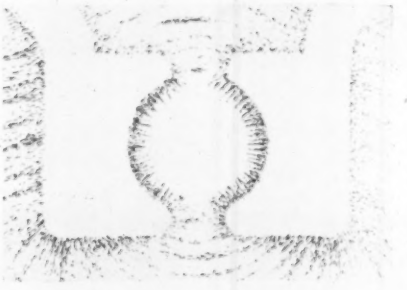


Fig. 31-2. Iron filings make visible the lines of force of a Weston permanent magnet with pole pieces and core. Note concentrated and uniform radial field.

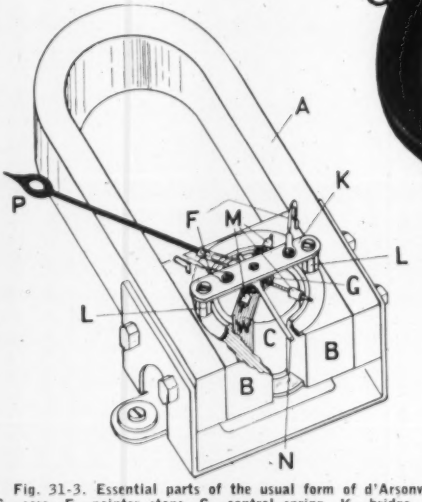


Fig. 31-3. Essential parts of the usual form of d'Arsonval movement. A—permanent magnet. BB—pole pieces. C—core. F—pointer stops. G—control spring. K—bridge. LL—insulating pillars. M—three counterweights. N—arm to which outer end of spring G is attached, and which can be shifted from outside of case to adjust zero. (Edgcumbe)

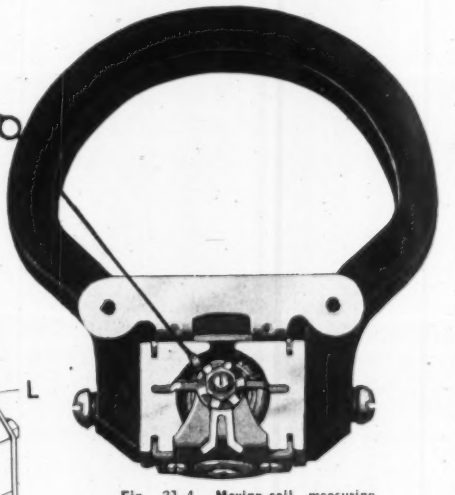


Fig. 31-4. Moving-coil measuring element, complete with all parts making up a "movement" or "mechanism" but not "an instrument" since no instrument scale is included in this assembly. (Roller-Smith)

restraining torque—then known as the *control torque*—are usually obtained from separate elements of the mechanism, the latter in most indicating instruments being derived wholly from a spiral spring, and in some delicate laboratory instruments wholly from a torsion fibre. In some switchboard instruments, particularly of the recording types, gravitation enters into the control, and either in conjunction with springs, or acting alone on the mass of the moving element, serves to oppose the actuating force and bring about equilibrium. Even the earth's magnetic field, usually an influence from which elements are shielded when precision is required, is actually used to furnish the control torque in the single-needle tangent galvanometer—a laboratory instrument mentioned here only because of this peculiarity. In *direct-deflecting* instruments a balance between the two forces is automatically obtained by the moving element changing its position under their influences until their respective turning moments are equal and opposite, when the position of the moving part, as indicated by an associated index upon a graduated scale, represents the value of the magnitude under measurement. In *zero-reading* instruments, the moving element is re-

stored to a fixed reference position by a counter-influence varied manually or through some other outside agency, and the deflection necessary to produce the required restoring force is determined from a suitable scale. The closest similarity to non-electrical instruments is found in electrical measuring elements depending wholly on gravitation for the restoring torque: *"gravity control" movements* are comparable to "primary" or "standard" pressure measuring instruments employing liquid columns or weighted plungers to oppose the measured pressure.

(c) Electromagnetic Elements Predominant

Since the number of electromagnetic instruments in use vastly exceeds those of all other classes combined, this handbook deals mainly with instruments and measurements based upon that principle, other classes being introduced only in those instances where they have found practical application. As the great majority of instruments are used in the measurement of current, voltage and power, and because ammeters, voltmeters and wattmeters in general need not differ materially in their operating principles or mechanical characteristics, the classification which is used when discussing these instruments is based upon the kind of current with which their elements operate, rather than upon the basic mechanical principles. This classification is: D.c. only (Section 2); both d.c. and a.c. (Section 3); a.c. only (Section 4).

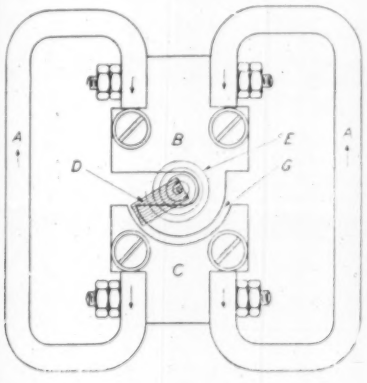


Fig. 31-5. In the Westinghouse "L" movement, an adaptation of the d'Arsonval principle, a rectangular coil D swings in a single air gap G between pole-pieces B and C of the permanent magnet system.

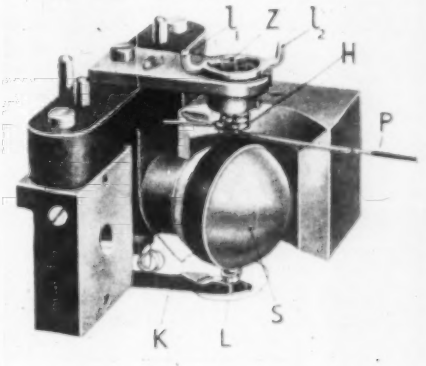
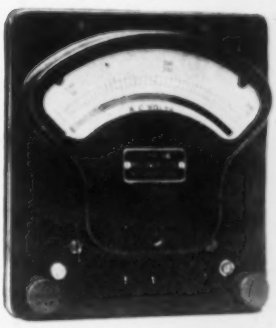


Fig. 31-6. In the Cambridge "Unipivot" movement, another adaptation of the d'Arsonval principle, a circular coil is supported on a pivot the point of which rests in a jewel mounted in the center of the spherical core.

2. Elements Operable on Direct Current Only

This group of movements includes in general those in which a permanent magnet is associated with the electrical circuit in which flows a current representative of the electrical magnitude to be measured; and these are for the most part of the permanent-magnet moving-coil, or d'Arsonval, type shown schematically in Fig. 31-1 and diagramatically in Fig. 31-3. This movement consists essentially of a rectangular coil of fine wire pivoted on jeweled bearings and free to rotate in the annular space between the soft iron core and the pole pieces of the permanent magnet. Fig. 31-2 shows how the core gives a "radial" flux which makes for a uniform scale. Two spiral springs serve the double purpose of conducting the current passing through the coil and of providing a control force. Since the actuating force in such an element is dependent upon the product of the fixed field by the movable field, it is possible by providing a relatively powerful permanent magnet to obtain force sufficient for measurement purposes by the expenditure of a very small amount of power from the measured circuit. For this reason the d'Arsonval type of movement has found great favor in d.-c. measurements. A Roller-Smith d.-c. movement is shown in Fig. 31-4. Two (among the many) modifications of the d'Arsonval movement are shown in Figs. 31-5 and 31-6, the former being a Westinghouse wide-angle scale movement and the latter a Cambridge "Unipivot" movement with spherical core. The coils of d'Arsonval type elements are generally wound on aluminum or other suitable metal forms in which eddy currents are set up, resulting in damping action. (See Section 7.)

The measured current being carried in the delicate moving coil of instruments of this type, it is obvious that the value of this current must be relatively small. In voltmeters, a high resistance of suitable fixed value is placed in series with the movement, and measurements are made with a negligible current taken



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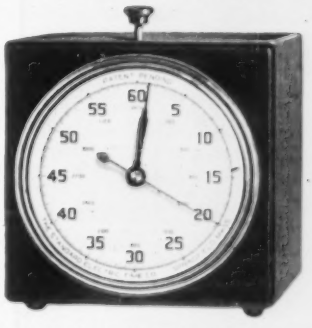

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from the line. In ammeters, shunts are generally necessary, and these will be discussed under The Measurement of Current.

An interesting type of direct-current element is found in the General Electric "Thomson Astatic" ammeters and voltmeters, used in locations, such as street railway switchboards, where severe stray magnetic fields are encountered. In this movement the effects of external fields are eliminated by the astatic arrangement of the poles of *two* magnets, the moving element comprising two coils.

Another interesting type of direct-current element is the Ayrton-Perry, or permanent-magnet moving-iron (sometimes referred to as the "polarized vane") type. Here a light soft iron vane is pivoted between the poles of a relatively large permanent magnet, provided with specially shaped pole pieces tending to maintain the vane in a definite position. The current to be measured flows in a coil so arranged that it produces a field perpendicular to that in the gap

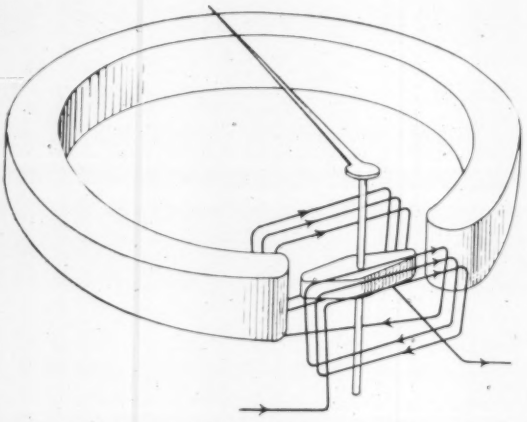

Fig. 31-8. Essentials of an Ayrton-Perry permanent-magnet moving-iron (or polarized vane) measuring element.

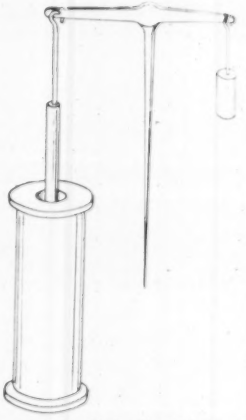

Fig. 31-9. Solenoid type of moving-iron element.

of the magnet, and the vane is deflected by this cross-field. This type of movement is relatively inexpensive, is frequently found in instruments used for automobile work and the like, and in one form the coil is entirely dispensed with and replaced by a cross magnet of soft iron having a loop exterior to the case, through which the current-carrying conductor is passed one or more turns, as may be necessary. Fig. 31-8 is a diagram of an Ayrton-Perry movement.

3. Elements Operable on Both Direct and Alternating Current

Since in elements of the permanent-magnet moving-coil type the main field is fixed and constant it follows that any reversal of the current flowing in the measuring circuit will produce a reversal of the actuating torque, so that with alternating current the moving elements of such instruments either oscillate violently or remain near the zero position, usually with a distinct tremor, but do not perform a useful measurement. In order to produce an actuating torque which will be a measure of the current flowing, it becomes necessary to provide a type of element in which both the main field and the field produced in the moving part perform their reversals simultaneously, when a definite and positive torque will be produced, having a value which bears a distinct relation to the effective value of the measured current. With direct current flowing in the windings of such instruments a definite measurement is of course obtained, but in some forms it is found that the calibration on direct current differs slightly from the a.-c. calibration.

Instruments having elements in which the fields of the moving and fixed parts of the measuring element are both produced by the current under measurements are classified as:

(a) Moving-iron
(b) Electrodynamic

(a) Moving-Iron Instruments

While there are three general forms of moving-iron instruments, the great variety of designs makes it impossible to discriminate definitely among them. In general they may be considered as—

(1) *Solenoid form*, in which an iron plunger free to move along the axis of a solenoid takes up a position representative of the value of current flowing. The principle is shown in Fig. 31-9.

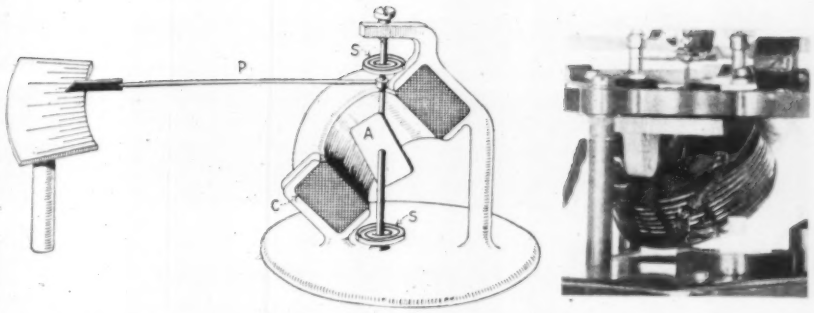

Fig. 31-10. Magnetic vane moving iron type of element—Thomson inclined coil movement. Iron vane A, attached at an angle to its spindle, tends to turn against springs SS so as to become parallel to lines of force passing down through center of coil C. (Swoope) At right, actual construction of G.E. "Type AD-6."

(2) *Magnetic vane form,* in which a relatively small vane of magnetic material tends to place itself parallel to, or in the most intense portion of, the field of a coil carrying the measured current. Historically, this element is the father of all electromagnetic instruments, dating from Oersted's observation of the antics of a compass needle near a conductor. Fig. 31-10 illustrates the General Electric's Thomson Inclined Coil movement which uses the vane principle.

(3) *Repulsion form,* in which two pieces of iron placed within the field of the measuring coil, becoming similarly magnetized, repel each other and tend to move farther apart. Fig. 31-11 (Weston) shows the principle and its development; Fig. 31-12 shows a Roller-Smith repulsion type movement.

Instruments of the moving iron type, while usually intended for a.-c. measurements, can be employed on direct current as well. Owing, however, to the magnetization characteristics of most irons, the d.-c. indication of such an instrument may be affected by its previous magnetic history. Therefore, moving-iron instruments should not be used for precise d.-c. measurements unless definitely guaranteed suitable for such by the maker.

An interesting application of the moving-iron principle is found in Crompton & Parkinson's "Tong Test" (Fig. 31-13) where an element of this type operates in the field of a hinged magnetic circuit (not a hinged current transformer) which may be opened to encircle a permanently installed conductor. This instrument is primarily adapted to a.-c. work, but is applicable with a slightly reduced precision to measurement of current in d.-c. circuits, whereas the portable instruments with hinged current transformers, which may resemble it somewhat, are usable only in a.-c. work.

(b) Electrodynamic Elements

The principle of the electrodynamometer is based on the fact that two conductors carrying electric current act upon each other with a measurable mechanical force. In movements of the electrodynamic type two or more wind-

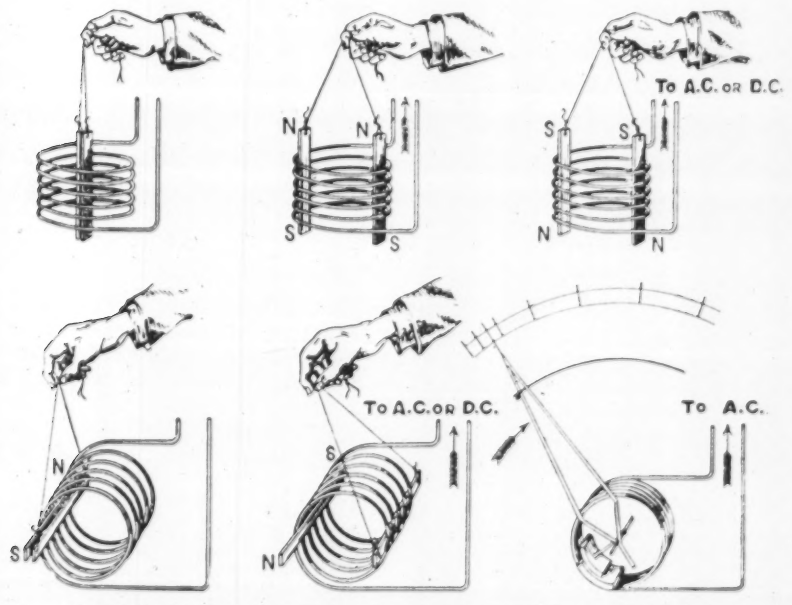

Fig. 31-11. Evolution of the repulsion moving iron type of measuring element. (Weston)

On January 1st the **Air Reduction Co., Inc.** exercised its option on the balance of the capital stock of the Wilson Welder and Metals Company of North Bergen, New Jersey. Air Reduction thus becomes the first of the oxyacetylene welding companies to own a 100% interest in an electric welding organization.

Jas. P. Marsh Corp., Chicago, announce the appointment of three new sales representatives: Fort Worth, Texas, J. M. Kane; Syracuse, N. Y., A. W. Reynolds; and Salt Lake City, Utah, A. A. Maycock Co.

The **Louis C. Eitzen Co.,** 280 Broadway, New York City, announces its appointment as exclusive New York representative for the **Trill Indicator Co.** of Corry, Pa., manufacturers of the Trill engine indicator and the Corry check valves.

MANUFACTURERS' NEW LITERATURE

In this department we each month list the printed matter issued by manufacturers. Unless otherwise noted, any of the items listed may be secured free upon application to the issuing firm. Manufacturers who have not yet sent in their printed matter are invited to do so.

B62 **Tachometer.** Leaflet describes Jones Type H-2 Hand Tachometer. Viking Instruments, Inc., New York City.

B63 **Remote Liquid Measurement.** 4-page bulletin; folder; and loose-leaf, on K-8 Telegage. King-Seely Corp., Ann Arbor, Mich.

B64 **Electric Stop Watch.** Leaflet describes laboratory timer. The Standard Electric Time Co., Springfield, Mass.

B65 **Production Recorders.** "The Graphic" No. 1633 is devoted to application of graphic instruments to ice production. Form 429 describes accessories for graphic instruments. The Esterline-Angus Co., Indianapolis, Ind.

B66 **Vitamin Tester.** 8-page booklet on the Hilger Vitameter A. Adam Hilger, Ltd., London, England.

B67 **Lubricants.** Technical Bulletin B113 deals with "Importance of Colloidal-Graphited Lubricants . . ." Acheson Oildag Co., Port Huron, Mich.

B68 **Ultrafiltration.** 28-page booklet U-3, "Zsigmondy Ultrafiltration Apparatus and Membranes" contains survey of work, 124 literature refs. Pfaltz & Bauer, Inc., New York City.

B69 **Telemetering System.** 4-page Bulletin 418 announces the "Metameter," operatable over distances up to 250 miles. The Bristol Co., Waterbury, Conn.

B70 **Scientific Instruments.** 32-page Sept.-Nov. 1933 issue of "Notizie Per I Laboratori" is mostly devoted to college physics lab. apparatus. Officine Galileo, Firenze, Italy.

B71 **Pocket Stroboscope.** Instruction booklet (in French) on "Strobo-Mecx" stroboscopic tachometer. F. Ducasse & Son, New York City.

B72 **Ohmite News.** January issue's technical article is on resistors in radio receivers. Ohmite Mfg. Co., Chicago, Ill.

B73 **Precision Tools.** 20-page catalog 29 describes light-wave interference method equipment, gage blocks, sine bars, flatness testers, etc. The Van Keuren Co., Boston, Mass.

B74 **Microscope Record.** 24-page January number contains articles on preparing metal specimens, high-power illuminants, illumination by parallel rays, etc. W. Watson & Sons, Ltd., London, England.

B75 **"What is this Thing Called Humidity?"** is title of folder containing 30 questions and answers. Taylor Instrument Companies, Rochester, N. Y.

B76 **Potentiometer Stabilog.** 4-page Bulletin 191-1 is technical preliminary description; 8-page Bulletin 194 is non-technical announcement of new control system. The Foxboro Co., Foxboro, Mass.

B77 **Stains and Preparations for Microscopy.** 14-page List covers "Bayer-Meister-Lucius" standardized and certified products including those for special purposes; textile tests, etc. Pfaltz & Bauer, Inc., New York City.

B78 **Cenco News Chats.** 16-page February number contains articles on Löddesöl Electrodialysis Apparatus, blown glassware replacement problems, constant wattage transformer, gas regulation, photoelectric control units, ultra-violet radiation dosimeter, thermoregulators, "six-instruments-in-one" galvanometer, etc., and the usual "Helpful Hints." Central Scientific Co., Chicago, Ill.

B79 **Resistors, Relays, etc.** Loose-leaf Bulletins 8001, 251 and 72, and 1934 price change notice. Ward Leonard Electric Co., Mount Vernon, N. Y.

B80 **Temperature and Pressure Controllers.** Folder briefly describes Spence Regulators. (Mfrs.'s name & address omitted. Imprint: The Bristol Co.)

B81 **Boiler Water Level Control.** Folder briefly describes McDonnell line. (Mfr.'s name and address omitted. No distributor's imprint.)

B82 **Common Frequency Broadcasting.** 12-page technical bulletin titled "Synchronization System" describes equipment, theory of operation, etc. Western Electric Co., Inc.; Graybar Electric Co., New York City.

B83 **Recording Thermometer.** 4-page description of new "Model 500" portable 6" round chart instrument compensated for ambient temperature variations and altitude. Moto Meter Gauge & Equipment Corp., New York City.

B84 **Flow and Level Control.** 8-page Bulletin 5944 announces new line of differential-pressure type recorder-controllers and describes various installations for flow and level control. Taylor Instrument Companies, Rochester, N. Y.

B85 **Self-operating Temperature Controllers.** 8-page Catalog 36R describes construction and characteristics of new line Taylor Self-Acting Regulators. Taylor Instrument Companies, Rochester, N. Y.

B86 **Recorder-controllers.** 8-page Bulletin 5951 announces new "Fulscope" line of adjustable-sensitiveness automatic control instruments. Taylor Instrument Companies, Rochester, N. Y.

B87 **Expansion-stem Temperature Controllers.** 8-page Catalog 7R describes new models of the "Type P" line and gives installation diagrams. Taylor Instrument Companies, Rochester, N. Y.

B88 **Pyrometer Protection Tubes.** Circular describes "Pynolag" line of tubes said to possess least heat-retarding characteristics. Louis C. Eitzen Co., New York City.

B89 **Thermostatic Bimetal.** 32-page handbook covers subject from theory through design and construction to practical applications. W. M. Chase Valve Co., Detroit, Mich.

INSTRUMENTS, 330 W. 42nd St.
New York City

Please have me supplied with a copy of each piece of Manufacturers' Literature listed below.

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ings carrying the current or currents to be measured react in such a way as to produce a torque (or thrust) capable of quantitative determination. The measurement of the torque may be performed either by providing, and determining the value of, an opposing torque to bring the moving coil to a standard position of reference, or by measuring the deflection of the moving coil against a varying control torque. Such movements can be constructed to give great precision of measurement; and the dynamometer principle with a precisely measured restoring force is embodied in some of the earliest types of standard instruments, such as the Siemens dynamometer, the Kelvin balance, and the Westinghouse precision zero-reading instruments. At present a number of makers

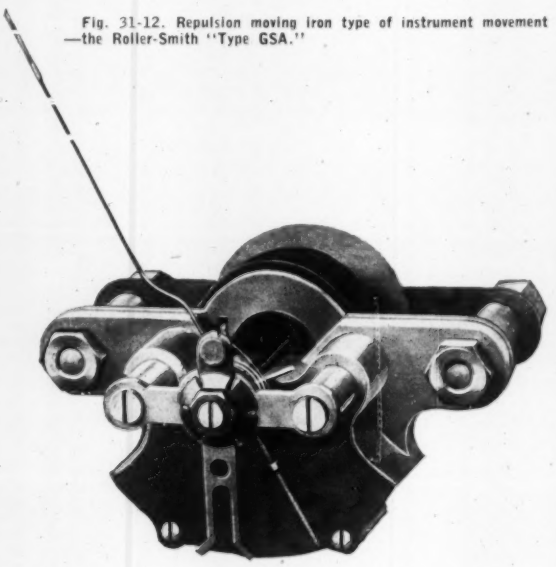


Fig. 31-12. Repulsion moving iron type of instrument movement —the Roller-Smith "Type GSA."

Fig. 31-13. "Tong-Test." (Crompton & Parkinson)

employ this principle in their higher grades of instruments; and most working standards for alternating current are of the direct-deflecting electrodynamic type.

In electrodynamic elements a single moving coil works in the field produced by the fixed coils, usually two in number. Since the presence of iron in the movement would generally introduce errors—by reason of the high inductance of the circuit, and of possible distortions of wave form—it is usual that such movements be "air-cored." This of course means a less efficient movement; and in general an electrodynamic instrument takes from the measured circuit a much greater amount of power than would be required by a d'Arsonval instrument of the same measuring range.

The leads which carry the current into the moving coil of an electrodynamic element generally serve the dual purpose of electrical conductors and control springs; and much of the quality of the instrument depends upon a proper

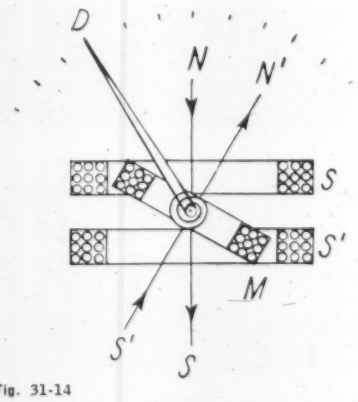


Fig. 31-14

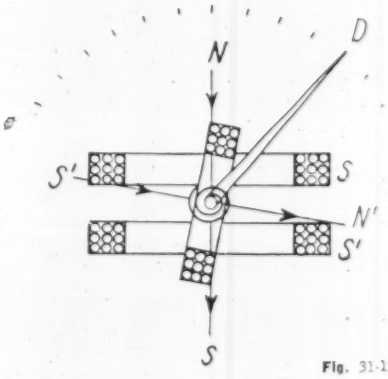


Fig. 31-15

Principle of the electrodynamic element.

In Fig. 31-14, S and S' are the two stationary coils which set up a magnetic field with its axis in the directions N-S. M is the moving coil, its normal position being as shown. As soon as current flows through the moving coil, it sets up a magnetic field with its axis, N'-S'. This results in a repulsion between N and N' and S and S', and an attraction between N and S' and N' and S, so that coil M tends to turn until its axis N'-S' coincides with the axis N-S of the stationary coils. A spiral spring opposes this alignment, so that the deflection becomes a measurement of the product of the instantaneous values of the currents in the stationary and moving coils. The magnetic circuits contain no iron and consequently the instruments have very small inductance. Fig. 31-15 shows the position of the moving coil when the pointer reaches full scale. (Westinghouse)

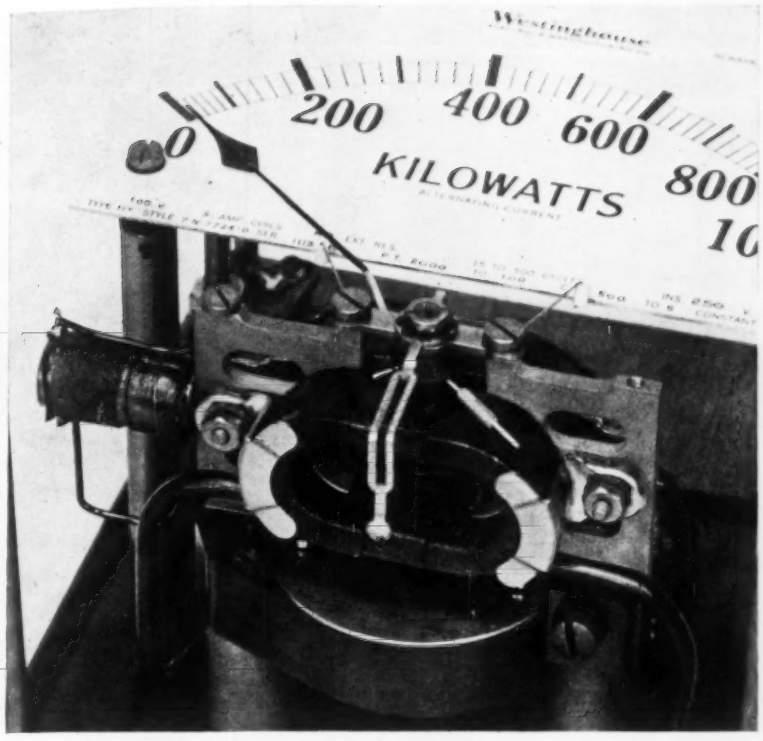


Fig. 31-16. Movement and scale of a Westinghouse "Type HY" electrodynamic instrument. Note that divisions are most "open" throughout middle region of scale.

combination of electrical conductivity, mechanical elasticity and permanence of characteristics under varying conditions of temperature, etc. In voltmeters, the moving and fixed circuits are usually in series with each other and with a resistance of high value connected across the circuit. In ammeters, except in the lowest ranges, there generally is provided a shunt across the moving coil, having such characteristics that the current will divide in correct proportion, regardless of frequency, while the whole current is carried by the fixed field coils. In the electrodynamic wattmeter, it is usual to carry the line current in the fixed coils, and apply the line voltage, through a suitable resistance, to the moving coil. The torque then becomes the product of the currents in the two circuits, and hence proportional to the watts in the circuit.

Figs. 31-14 and 31-15 illustrate diagramatically the direct-deflecting electrodynamic element; and Fig. 31-16 shows a Westinghouse electrodynamic movement.

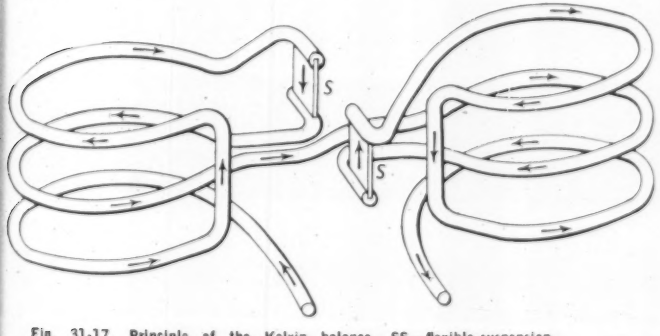


Fig. 31-17. Principle of the Kelvin balance. SS—flexible-suspension conducting strips.

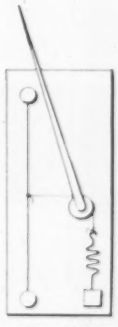


Fig. 31-18. "Hot-wire" principle.

The Kelvin (or Thomson) balance, shown schematically in Fig. 31-17, deserves special attention as a highly precise form of electrodynamic element. In the current balance, a stationary and a movable winding are interleaved in a manner to produce a maximum mutual electromagnetic reaction with a minimum of mutual and self induction. Each stationary coil is made up of two units wound in opposite directions and producing a radial magnetic field in the space between. In this field swings a movable coil; and the reaction is such that the movable coil will tend to move up or down with a force dependent upon the

NEW INSTRUMENTS

Write Information Section, Instruments Publishing Company, for additional information.

Ultra-Violet Radiation Meter and Indicator

General Electric Co.

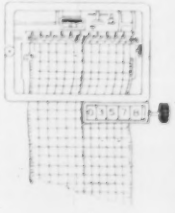
TWO new instruments are announced for measurements of radiation in the region between 2800 and 3200 A.U. One registers the amount of such radiation falling on a unit surface in a given time and, therefore, is a meter; the other furnishes an instantaneous reading of the strength of any given source, and thus is an indicator. The integrating meter consists essentially of a cadmium type

phototube serving as a radiation receiver, a d.-c. amplifier employing a screen-grid tube and dry batteries, and a four-digit cyclometer counter. In operation, the photocell output accumulates on a capacitance until it reaches a sufficient quantity to cause discharge, thereby actuating the counting relay, and the process is repeated as long as the receiver is exposed to ultra-violet radiation. The unit thus counted is the "E-viton" proposed by Luckiesh. (One E-viton [10μw] per cm.^{2} = 1 erythemal unit.) The tube and case are easily portable, the case dimensions being approx. 8"x10"x7". The indicator (illustrated) has a case approx. 8"x9"x7" and weighs 12 lbs. complete.

Distillation Curve Plotter

Podbielniak Industrial Research Labs.

TRUE distillation curves are obtained by means of this new recorder. It consists of a specially modified potentiometer recorder (Brown Instrument Co.) with the chart roll controlled through suitable gears by a large hand knob which also actuates a five-digit cyclometer counter. The fractionating unit thermocouple is connected in the usual manner to position the pen on the temperature scale. Instead of taking an autographic temperature-time record, the operator simply turns the knob to make the figures of the counter correspond to the pressure in millimeters at each stage of the process, as read by him on the distillation apparatus man-



ometer. It is said that this recorder, therefore, eliminates much of the human element, simplifies operations, diminishes chances of error and yields unbiased and complete curves for permanent record.

Potentiometer Stabilog

The Foxboro Co.

NEW fields of industrial process temperature control are said to be opened up by the introduction of this novel combination of measuring and control elements. The measuring system is the Foxboro non-recording potentiometer employing resistance bulbs or thermocouples; the control system is the same company's Stabilog. Both having been described in these columns, we may limit our detailed description to the means whereby the electrical temperature system is enabled to command the air-operated control system without sacrificing the accuracy of the former or the follow-up control characteristics of the latter. This is accomplished by a depressor-bar mechanism operating at a frequency of 18 cycles a minute (synchronous-motor or pneumatic-motor drive) to position the Stabilog flapper in accordance with the direction and extent of deflection of the potentiometer's galvanometer pointer. Fig. 1 shows the essential parts: Any departure of the temperature in the furnace or other controlled apparatus from the setting point causes the galvanometer pointer to deviate from zero on the deflection scale. The relation of this deflection to the extent of departure is determined by the constants of the potentiometric system and also by an easily accessible sensitivity adjustment, but in any event

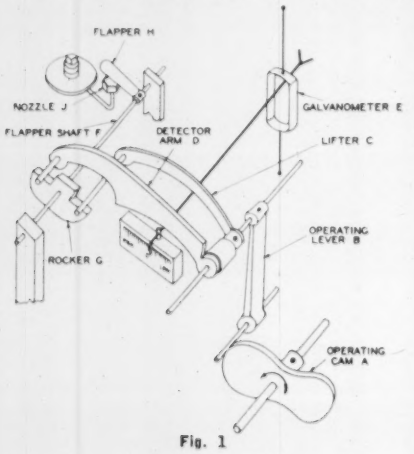


Fig. 1

it is linear, by reason of the temperature-e.m.f. relation and of the galvanometer scale law for the small angles involved. The pointer swings freely except for a portion of every depressor-bar mechanism cycle when detector arm D rests on it. Lifter C rises and falls cyclically, first lifting detector arm D and then allowing it to move down relatively slowly (not allowing it to drop on the pointer).

Lifter C and detector arm D are *each* capable of altering the position of rocker G, but not both simultaneously. Once in each cycle, *either* C or D alters the position of G, but *only* if the pointer deviates from zero: if the thermocouple temperature corresponds to the setting point there will be no change in the position of G and (since this determines the relation of flapper H to nozzle J) the Stabilog system will not function to change the rate of B.t.u. supply to the furnace

strength of current flowing. This arrangement renders the movement substantially immune to stray magnetic fields. The two moving coils are attached to a rigid structure and suspended by flexible leads. As their weights are balanced, the mass of idle material is kept at a minimum.

In the laboratory standard instruments of this type the force of reaction of the coils is balanced by weights; and the process of measurement really consists in *weighing* the electromagnetic reaction. While great precision is thus obtainable, manipulation of the instrument is slow and cumbersome, and a very steady supply of current is required. The Kelvin balance is made as an ammeter (illustrated) with relatively heavy coils in series; and as a voltmeter, in which the coils are wound of fine wire, with a suitable resistance box in the circuit. The instrument is also available as a wattmeter, having stationary current coils and movable voltage coils.

While the Kelvin balance with gravity control is now little used, the electromagnetic type of element finds application in a number of spring-controlled laboratory standards and recording instruments.

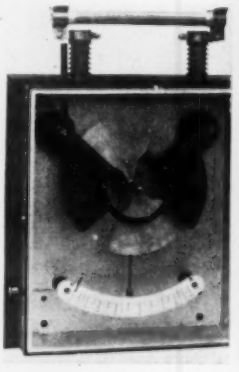


Fig. 31-19. General Electric vane type electrostatic voltmeter.

Fig. 31-20. General Electric pan type electrostatic voltmeter.

Fig. 31-21. Modified form of voltmeter shown in Fig. 31-20.

(c) Other Types

In addition to the moving iron and electrodynamic types of measuring elements, both of which, of course, are electromagnetic in principle, mention may be made of two other types which, while not widely used, are recognized as practical measuring devices.

The thermal expansion or *"hot wire"* type of element depends upon the expansion of a wire heated by the current to be measured, a very small movement of the wire being mechanically multiplied into a relatively large pointer deflection (see Fig. 31-18). This type, like the others dealt with in this Section, may be used with equal facility on direct and alternating current. The power consumption is inherently greater than in the electromagnetic types, and is almost prohibitive in the hot-wire voltmeter. In the measurement of high-frequency currents, hot wire instruments are not subject to certain errors which may characterize electromagnetic types; but recently even in this application they have been to a great extent displaced by more efficient and accurate instruments of other types.

The *electrostatic* type has found considerable application as a voltmeter — preferably as a kilovoltmeter because its operating forces are relatively weak, but it nevertheless is available as a practicable indicating instrument in ranges as low as 150 volts full scale. Its great advantage lies in its low energy consumption, this being zero on direct current and usually of negligible value on alternating current at commercial frequencies. Fig. 31-19 shows the General Electric vane type of electrostatic voltmeter; the G. E. pan type is shown in Fig. 31-20 in its regular model, and in Fig. 31-21 as improved by Borden to

make its readings more dependable. The Ferranti electrostatic voltmeters deserve mention because of their small vane type elements and their ability to measure low potentials: the latest one is a "2½ inch" instrument scaled 0-150 volts.

Both the hot wire and the electrostatic principles can be used as wattmeters; but as such they cannot be said to have advanced beyond the laboratory stage.

4. Elements Operable on Alternating Current Only

The general type of instrument which performs measurement on alternating currents solely by virtue of the fact that these are alternating, is known as the *induction* type. In general, the principle is not unlike that of the "split-phase" motor.* The current under measurement is caused to produce an alternating field in an air-gap wherein lies a rotor or electrically conducting non-magnetic metal. By means of a pole-shading circuit the alternating field is resolved into two out-of-phase components, thus producing a rotating field. The conducting rotor, lying in this field, is constrained to follow the traveling flux, and its torque is opposed by spiral springs. Fig. 31-22 is a diagram of a Westinghouse induction instrument. The induction element has found wide application as a voltmeter, ammeter and wattmeter; and while at present it is giving place to the moving-iron and electrodynamic types in indicating instruments, it practically monopolizes the field in the alternating-current watthour meter. Direct current passed through the circuits of an induction instrument produces no effect other than a slight tremor at the instant of being applied and removed.

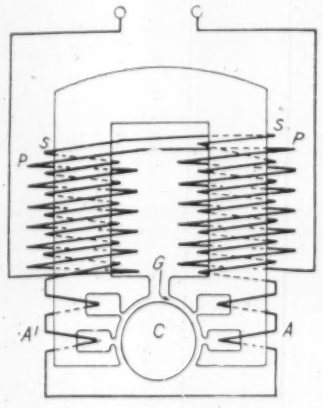


Fig. 31-22. Circuit diagram of a.c. measuring element employing induction principle. Drum of moving element rotates in annular air gap G. Primary current passing through primary coils PP induces current in secondary coils SS. Induced current passes through auxiliary coils AA which are wound in opposite directions and distributed in slots in the two poles of the magnet to make the "pole-shading" circuit. (Westinghouse)

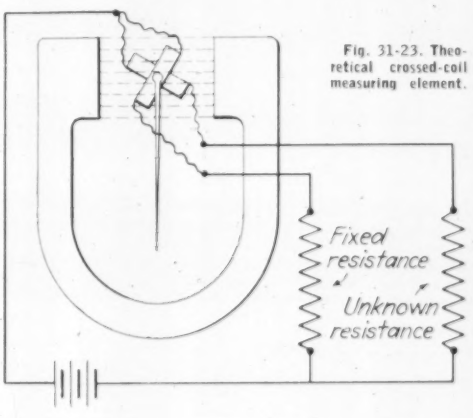


Fig. 31-23. Theoretical crossed-coil measuring element.

5. Ratio and Position Meters

A type of movement which has a rather broad application is known generally as the "crossed-coil" type. In it two coils are mounted upon a common shaft with their respective axes intersecting each other. These coils lie in a common field, and the movement has no control springs, the currents being led to the moving coils by soft untempered conducting filaments as nearly torsionless as possible. Thus, with no current flowing in the windings, the movement, when properly adjusted, should be in equilibrium at *any* point on the scale. When current flows in the windings the moving element will take up a position depending upon various factors but generally governed by the ratio of the currents in the two moving coils.

The *direct-indicating* ohmmeter makes use of the crossed-coil principle, in a circuit wherein a definite voltage is applied to one of the coils through a series resistance, while the other coil is in series with the resistance to be measured, the whole moving element being in the field of a suitably formed permanent magnet. The movement thus takes up a position representative of the ratio of the value of the applied voltage to that of the current through the resistance to be measured, so that the scale may be graduated in ohms or in multiples thereof.

The theoretical crossed-coil movement consists of two coils at right angles, rotatable in a parallel field, as in Fig. 31-23. Here the tangent of the angle of deflection from mid-position is proportional to the ratio of currents flowing in the crossed coils. In d.-c. work, if a core is introduced to strengthen the field,

*A single-phase induction motor equipped with an auxiliary winding, displaced in magnetic position from, and connected in parallel with, the main winding.

Fig. 2

or other controlled equipment. Should the thermocouple temperature fall below the setting point, galvanometer E deflects to "low" side, D descends far enough to engage G and rotate F counter-clockwise until G is stopped by E, and H is moved *toward* J, initiating a corrective function by the Stabilog to supply more heat. Should the temperature rise above the setting point, the pointer being on the "high" side prevents engagement of D and G, and it is C which rotates G clockwise until stopped by D, moving flapper away from nozzle and causing Stabilog system to cut down rate of heat supply.

Thus, the initial "command" given by the thermal system to the Stabilog is *proportional* to the departure from the temperature which is to be maintained. It is not an electrical impulse which can only have one fixed value as in "on-and-off" systems, or a plurality of fixed values as in 3-point or 5-point systems. There is an infinite number of values. Moreover, this initial command is not imparted to a conventional pneumatic system which obeys it "blindly" without taking the process demand into account: the Stabilog being a follow-up system adjusts the relation of normal valve opening (corresponding to zero galvanometer deflection) to the process demand, as in the case of starting a furnace from cold, or other abnormal conditions.

The Potentiometer Stabilog is made up in rectangular case with two doors, as shown by Figs. 2 and 3. With both doors

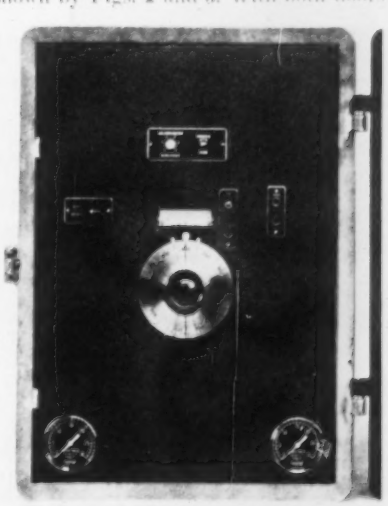


Fig. 3

closed, the operator can see the setting, observe the instantaneous deflection and read the gages for air supply and for air to control valve. Opening the outer door exposes all adjustments pertaining to process control, while the inner door protects the potentiometer and Stabilog mechanisms. Where records are desired, it is possible to tie in as many as six Potentiometer Stabilogs with one of the maker's standard multiple-point recording potentiometers.

Temperature Controllers with Heat-motor Valves

Wilbin Instrument Corp.

ELECTRIC power, from any light socket, operates the controlled valves (of any size); not, however, through a conventional motor but through a unique "heat motor." Thus there are no rotary parts, levers or cams. "Nothing moves but the valve," it is said, and in the event of current failure the valve returns to the safe position, never remaining partly open. Instead of a valve, a damper can be operated by the novel heat motor. A number of different combinations of thermostats, heat motors, etc., are announced. The following descriptions are of two systems, each typical of the new line but each comprising distinctive elements and possessing distinctive characteristics.

1. *Temperature Regulator with Type E Heat Motor.* Schematic diagram, Fig. 1, shows in section a room (Type LSR) thermostat but one of those with a remote bulb may be used. All are said to be "sensitive to a fraction of 1° F." Thermostat chamber 2 is completely filled with liquid. In this chamber is flexible bellows 3, having its lower end closed and its upper end sealed to the top of chamber. Attached to inside of bellows is plunger 4 which actuates Micro snap switch 5. This switch is normally closed and opens with rising temperature.

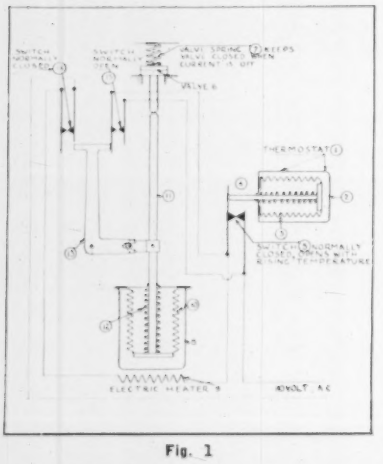


Fig. 1

Valve 6, which thermostat 1 controls, is of the reverse acting type: opened by the action of the thermostat and closed by spring 7. Suspended below valve 6 is the heat motor. This consists of pressure chamber 8 to the base of which an electric resistance heater 9 is strapped. A flexible bellows 10 has the lower end closed and the upper end sealed to the top of pressure chamber 8. Valve-operating plunger 11 is fastened to the bottom of the bellows, which is held expanded by the spring 12. When current is on, as is done in d'Arsonval instruments, the flux tends to become uniformly and radially distributed about the core, and the instrument loses its ratio-measuring characteristic and becomes unstable. In the Harris ohmmeter (Cambridge), Figs. 31-24 and 31-25, this is overcome by forming each of the coils to cover two opposite quadrants of the core, so that as the movement rotates one coil moves into the flux as the other moves out. In the crossed-coil movement of Hartmann & Braun, Fig. 31-26, the desired non-uniform flux distribution is obtained by the use of an elliptical iron core in a cylinder air-gap.

Probably the best known application of the crossed-coil movement to the measurement of resistance by ratio determination is to be found in Evershed's "Megger" (Biddle), shown diagramatically in Fig. 31-27. Such instruments

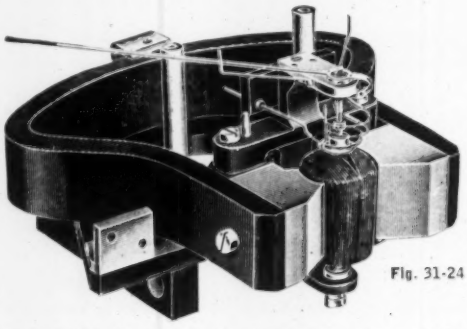


Fig. 31-24

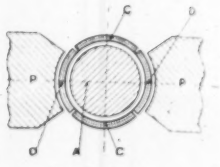


Fig. 31-25

Movement of Harris Ohmmeter (Cambridge). In Fig. 31-25, DD is the deflecting coil and CC the controlling coil.

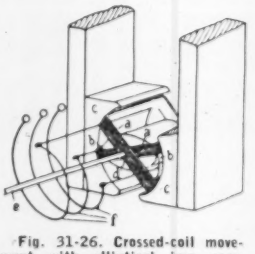


Fig. 31-26. Crossed-coil movement with elliptical iron core. (Hartmann & Braun)

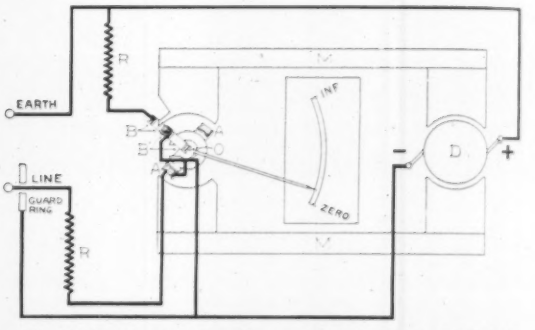


Fig. 31-27. Electrical connections and magnetic circuit of Evershed's "Megger" (Biddle). Between the poles at one end of the pair of permanent bar magnets MM is armature D of the hand-driven generator, and between the poles at the other end is the moving system of the ohmmeter. This has three coils, A, B and B′, fixed together and free to rotate about axis O. Coils B and B′, connected in series through resistance R across the generated potential, constitute the control element of the ohmmeter. When potential is applied they tend to turn counter-clockwise until they assume a position where the pointer indicates infinity on the scale. Coil A which for most of its travel is in a uniform radial magnetic field, is in series with the generator, the ballast resistance R′, and the unknown resitsance connected to the terminals Earth and Line. The current flowing through A tends to turn the axis clockwise, in opposition to B and B′. When the Earth and Line terminals are short-circuited the torque produced by A overpowers that of B and B′ and the pointer stands over Zero. If now a suitable resistance is connected to the external terminals, the current from the generator has two paths available and will divide, part passing through coils B and B′ and part through coil A in series with the resistance under test. The result is that the opposing torques of the two elements balance each other at a point on the scale corresponding to the value of the resistance connected.

may be obtained in a wide variety of types and ranges, including a modified form which combines a Wheatstone bridge circuit for ordinary metallic resistances with a "Megger" circuit for insulation resistances up to several thousand megohms.

The crossed-coil movement has a number of important applications in a.-c. work; and here, with a solenoidal field coil, there may be obtained a reasonably straight uniform field, and an actuating torque comparable with that of other electrodynamic instruments. In the *power factor meter*, shown diagramatically in Fig. 31-29, the field coil is usually caused to carry a current representative of the line current. One of the moving coils carries a current representative of the line voltage, while the other carries a current which is caused to differ in phase from the line voltage, thus associating a rotating field with the moving element and an oscillating field with the stationary part. (On polyphase circuits the two moving coils, being set at a suitable relative angle, may be excited from two phases of the system.) The moving element then tends to place itself in a position where the field in the fixed coil is in phase agreement with the resultant of the fields of the two moving coils; and as this position will vary with the phase position of the line current as related to the line voltage, the indication of the instrument becomes representative of the power factor of the current in the individual conductor in which the current coil happens to be con-

nected, and—only if the load on the system be balanced—of the whole load. In the case of unbalanced loads the reading of a power factor meter connected in but one line of the system may be very misleading; and an attempt to combine readings of instruments connected in each of the lines may be equally erroneous. In such cases, where a reasonably balanced sinusoidal voltage exists, an acceptable reading of power factor will be obtained, whatever the conditions of current unbalance, with an instrument having three current coils connected in the respective lines. Such instruments are not common, but where used they give most satisfying results.

The *synchroscope* is almost identical in structure with the power factor meter. The moving coil produces the equivalent of a rotating field from one of the two sources to be synchronized, while the fixed coil is excited from the voltage of the other source. The position of the pointer of the instrument will then be representative of the relative phase position of the two sources, and true

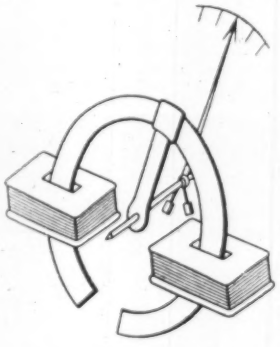


Fig. 31-28. Ring-vane ratio movement. (Joens)

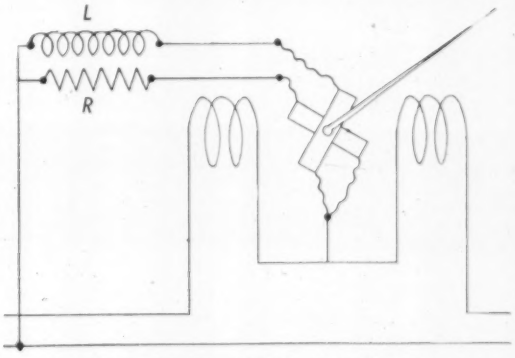


Fig. 31-29. "Power-factor meter" principle.

synchronism may be definitely indicated on the dial. In the Lincoln synchroscope (Westinghouse) the moving element rotates freely, and the pointer indicates through the complete circle. In the Weston synchroscope the pointer swings through a limited angle, but its oscillatory motion is made to simulate rotation by concealing the pointer behind a translucent dial and illuminating it so as to cast a shadow on the dial by a lamp connected between the two sources. Thus, while the pointer is actually oscillating, the intermittent illumination gives the illusion of continuous rotation, and for positions near synchronism the result is fully as effective as a rotating indicator.

A number of *frequency* meters also are based on the crossed coil principle, the currents flowing in the respective coils being governed by circuits having differing time constants, so that their relative values change with differing frequencies of the system. The field is furnished from the line voltage; and the moving element takes up positions representative of the ratio of the currents, and hence of the frequency of the system.

The MacGahan *portable phase indicator* (Westinghouse), is a variation of the rotating synchroscope, with one of its coils wound for current and the other for voltage. It has a scale marked off in "electrical degrees," being a phase meter; but by reason of the fact that it uses stationary coils and a magnetic iron vane, instead of a dynamometer movement, its scale is a full circle and the electrical degree graduations correspond to the geometrical 0 to 360 degrees.

Finally, the ratio-meter type of element, having no control springs, has found a wide application in several forms of telemetering apparatus, and as such will be dealt with further on.

6. Scale Law

The manner in which the length of a scale division varies from point to point along the scale is known as the *scale law*. If this length is constant the scale is said to be uniform or linear, and to have a straight line law. If scale divisions increase in length in going up the scale, in such a way that a change in value of the electrical magnitude gives a change in deflection proportional to the square of the value, the instrument is said to have a quadratic or square-law scale. In instruments of zero-reading types, where the actual measurement is always performed with the moving element in the one position, the reading being determined from a measurement upon the force required to restore it to that position against the influence of the actuating torque, the scale laws would be of but two types, the linear and the quadratic. In d'Arsonval movements, where the value of the measured magnitude is proportional to the product of that value by a constant quantity (the permanent magnet field) the linear law

heater 9 vaporizes a portion of the volatile fluid in chamber 8, builds up a pressure in chamber 8, causing bellows 10 to be compressed and valve plunger 11 to move up, thus opening valve 6.

In a control box mounted on the valve motor is crank mechanism 13 actuated by the travel of plunger 11. This crank operates two Micro switches arranged in the control box. Switch 14 is connected in series with thermostat 1 and is normally closed. When plunger 11 is at the top of its stroke, crank 13 opens switch 14. This interrupts the flow of current to the heater. Chamber 8 immediately starts to cool (assisted by radiating fins) and stem 11 begins to travel downward. Switch 14 then at once closes again, so that the valve is held at the wide open position so long as the thermostat switch 5 remains closed. When the temperature surrounding thermostat 1 reaches the point at which it is set, plunger 4 opens switch 5, thus interrupting the current to the motor. The latter cools rapidly and the plunger travels downward until the valve 6 is closed. A slight further downward movement of the plunger then causes crank 13 to close switch 15 in the control box. This switch is shunted across the thermostat connections and is normally open. Closing it puts current again on the heat motor momentarily, causing a slight movement back and forth of the valve plunger, without actually opening the valve. This keeps pressure in the heat motor so that it is instantly ready to open the valve when the thermostat calls for more heat. The cycle is then repeated.

2. *Temperature Regulator with Type C Heat Motor.* Fig. 2 is a schematic diagram of one of these systems which requires a special type of Wilbin thermostat. (These thermostats have a range of 100° F. between −40° F. and 650° F. and may be had in indicating models.) A characteristic of systems with Type C heat motors is said to be that a 1° F.

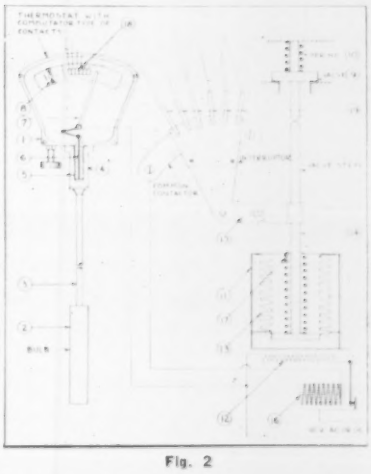


Fig. 2

change at the thermostat bulb "will move any size control valve from open to closed, yet the valve travel can be arrested at six positions between open and closed. Perfect *throttling control* is the result." These systems are recommended "for the most exacting applications such as in the petroleum, dairy, rubber, textile and food industries." Bulb 2, tube 3 and pressure chamber 4 of thermostat 1 are completely filled with a liquid of suitable temperature coefficient of expansion. Chamber 4 contains flexible bel-

lows 5, which has its lower end closed and its upper end sealed to wall of chamber 4. Through plunger 6, bellows actuates the indicating and contact mechanisms. When bulb 2 is immersed in the medium to be controlled, an increase in temperature expands liquid filling, causing plunger 6 to actuate contact arm 7 and dial indicator 8. Control valve 9 (of any suitable type) is normally held closed by spring 10. Suspended below it is the heat motor similar in principle to Type E described above, except that to valve actuating-plunger 14, contact interrupter 15 is attached. Mounted in a box on the heat motor is mercury switch relay 16. This relay is normally closed.

When current is on, heater 12 builds up a pressure in 11 which compresses bellows 13 against spring 17, moving plunger 14 upward and opening valve 9 wide. At the top of the valve stroke, relay 16 is opened mechanically by plunger 14. Radiating fins on chamber 11 immediately cool the motor and the valve begins to travel downward. However, so long as the thermostat calls for heat, relay 16 immediately closes again mechanically so that the valve is held near the wide open position.

As the controlled temperature approaches the point at which thermostat 1 has been set, the first of contacts 18 in the thermostat is closed, opening relay 16 and allowing the valve to travel downward one sixth of its stroke. At that point, interrupter 15 will again open the circuit and close the relay, causing the valve to hold this throttling position. Should the temperature at the thermostat continue to rise, the next one of contacts 18 will close, causing valve to close a little farther, and so on until either a throttling position is found at which temperature is held constant, or until the valve is closed entirely. The cycle is then repeated. (Resistances in series with relay 16 reduce the current through commutator contacts 18 and 19 to one watt for a.c. and half watt for d.c. This prevents sparking troubles.)

Vacuum-contact Relay

General Electric Co.

DESIGNED for industrial applications where presence of combustible vapor, gas or dust demands vigilance against exposed arcs, this new hinged-armature auxiliary relay has single circuit-opening and -closing contacts mounted inside an evacuated glass tube. A metal bellows sealed to the tube carries the moving contact and permits its movement. The a.c. ratings are higher than would be the case if contacts were not in vacuum—which extinguishes arc when current goes through zero. Vacuum contact principle permits use in corrosive or dirty atmospheres.

would hold under conditions of zero reading, while in all movements wherein both the fixed and the moving fields vary directly as the measured magnitude, the scale would be quadratic. In the zero-reading wattmeter, wherein the measured magnitude is represented by a product, which is responsible for the actuating torque, the scale law would be linear. Examples of the above, in which the scale law conforms with mathematical precision to the linear or the quadratic law, are found in precision instruments of the torsion head type such as the Westinghouse standards, or of the gravity-controlled type, such as the Kelvin balance.

When the fixed and the moving parts of the actuating element of an instrument take up different relative positions through the scale, as is the case with all direct-deflecting instruments, it may be said that no scale is exactly linear or quadratic, though the permanent-magnet moving-coil type of movement, when well designed and carefully constructed, very closely approaches the linear law, and induction type voltmeters and ammeters a quadratic law.

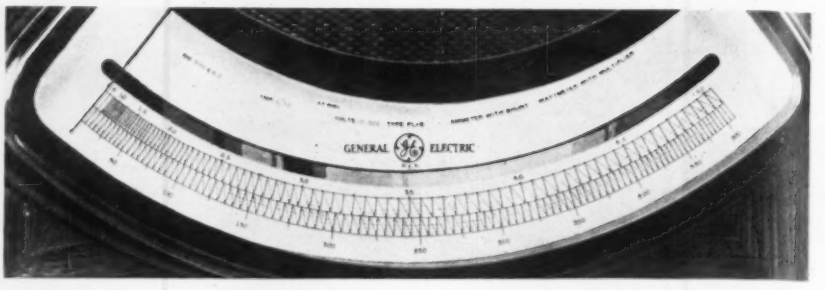


Fig. 31-32. Scale of General Electric "Type PL-2" laboratory standard ammeter-wattmeter. Length of mean arc is 12 inches. The measuring element has an inherently quadratic scale law. The ampere scale is approximately quadratic; the watt scale has been rendered approximately uniform by the design. Both are vernier scales, each division subdivided into fifths, so that they can be read to tenths and even to fifteenths.

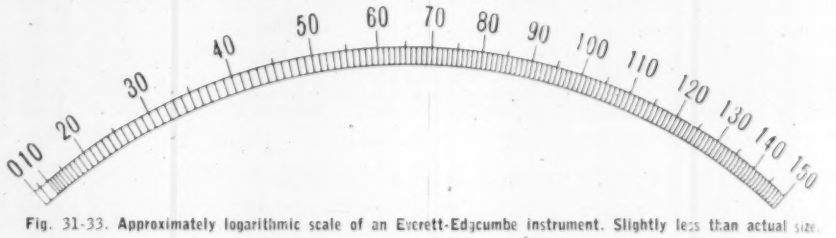


Fig. 31-33. Approximately logarithmic scale of an Everett-Edgcumbe instrument. Slightly less than actual size.

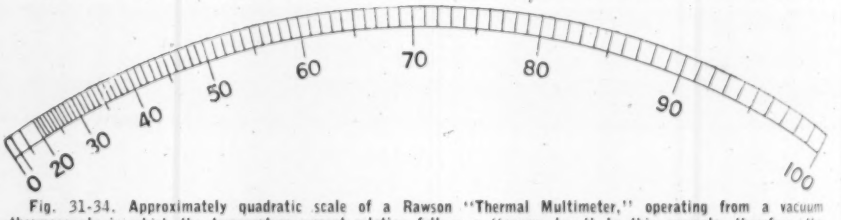


Fig. 31-34. Approximately quadratic scale of a Rawson "Thermal Multimeter," operating from a vacuum thermocouple in which the temperature-current relation follows a "square law." In this example, therefore, the type of scale is primarily determined by an extrinsic factor, not by the scale law of the instrument movement. Actual size.

The scale law is governed by a number of factors, chief of which are (1) the manner in which the relative direction and intensity of the actuating forces vary with changes in the position of the moving element and (2) the manner in which the direction and intensity of the control force vary at the same time. These may be said to be the "geometry" of the actuating element and of the control member respectively.

A study of electrodynamic movements shows that even with a uniformly distributed main field, the angle of action between the fixed and moving elements will have a great effect on the torque for different positions of the moving coil, and that this variation will be greater the wider the angle through which the coil swings. In instruments of the moving-iron type, the strength and distribution of the magnetic field will vary with the position of the moving part, so that neither of these types of instruments can follow an inherently quadratic law. By modifications of the coil geometry in design it is possible to cause the scale to follow almost any desired characteristic; and alternating-current ammeters and voltmeters having an almost linear scale law have been produced. In general, however, if an efficient design is desired, the scale should follow the natural law of the instrument.

Some makers of instruments have advocated the logarithmic scale, in which the divisions at the lower end are long, progressively shortening as the top of the scale is approached, similar to those on the scale of a slide rule. The theo-

gical basis of such a scale lies in the fact that a given error of reading entails the same percentage of error at all points; but this advantage is generally offset, not only by the engineering difficulties in producing such a scale, but by the abnormal errors introduced in the event of a slightly bent pointer being corrected for by adjustment of the zero.

7. Damping

It is not sufficient that an instrument for industrial purposes be accurate in its indications: delays must be minimized. The ideal instrument should instantly indicate its reading when connection is made to the circuit, and should follow any variations in the measured magnitude without *lag* or *oscillation*. Such a condition is striven for by designers, but in practice be obtained, though some high-grade instruments attain their readings so rapidly that the eye cannot follow the transition from zero to the final indication. When the pointer (or other indicator, or pen) of an instrument swings beyond the final reading and comes to rest only after a series of oscillations, the instrument is said to be "underdamped" and when the indicator approaches the final reading in an appreciable period of time, without actually passing that point, it is said to be "overdamped." In general it is desirable to have the movement slightly underdamped, in order that its free swing, while not appreciably delaying the making of an observation, may give an assurance of freedom from friction or sluggishness. For recorders, the damping requirements vary with the "speed" and other desired characteristics. "Critical damping" is that obtained when reducing the amount of damping would result in oscillations and increasing it would increase the lag.*

Because of the relatively weak forces employed in electrical instruments, it is essential that mechanical friction as a factor in damping be entirely eliminated and that resort be had to molecular damping, which may be said to vary with the speed of pointer displacement and to disappear as the parts come to rest. The damping principles used in electrical instruments may be classified as magnetic and fluid, the latter being subdivided into air damping and liquid damping.

Magnetic Damping. In magnetic damping a light metal vane, disk or cylinder, attached to the moving part, swings in the field of one or more permanent magnets, the induced eddy currents tending to oppose the motion and therefore to reduce the oscillations of the moving element. In instruments of the permanent-magnet type the actuating coil may be wound on a closed metal form which is equivalent to a short-circuited turn in the field of the magnet; or the external circuit may be arranged in such a manner that currents set up in the winding of the coil by its motion in the field are used to oppose the motion and reduce the tendency to swing. Where magnetic damping is used in instruments not embodying a permanent magnet as a part of the primary measuring element it becomes necessary to add a magnet and a vane, with a consequent increase in the weight of the moving part and of the instrument as a whole. In view, however, of the excellent performance which may be obtained with this form of damping, some makers prefer to use it despite the increased weight.

Air damping is obtained by the use of a very light vane swinging in a chamber (usually fan-shaped) where it acts as a piston, and has its motion retarded by the entrapped air passing between the edges of the vane and the walls of the chamber. In order to obtain successful damping it is essential that very small clearances be used; but engineering difficulties in the production of a rugged and substantial design of such a damping device have been successfully overcome, and many air-damped instruments (principally for a.-c. work) are in use.

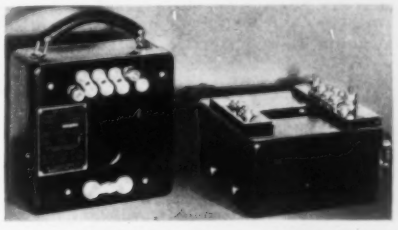
Liquid damping is limited almost entirely to graphic instruments, where, because of the relatively high inertia of parts, magnetic or air damping would be undesirably cumbersome. While the mechanical precision required for air damping is not here necessary, there is practically always a certain risk of the damping liquid becoming spilled. The most common damping liquid is oil, and it generally is desirable to select an oil with as low a temperature coefficient of viscosity as possible (without sacrificing other properties). In some cases glycerin is used; and by diluting it with water a wide range of definite viscosities is available. Glycerin is hygroscopic, tending to change its consistency with weather conditions; its aqueous solutions are electrically conducting, and it has a tendency to corrode steel parts; therefore it should not be used except in specially designed damping systems.

*A complete discussion of the basic principles of damping will be found in Part One (Fundamentals of Instrumentation), Chap. III, Section 2.

Portable Current Transformers

The Esterline-Angus Co.

FOR use with indicating and recording instruments, on circuits of all voltages up to and including 2500 volts, this new transformer has nine primary current ranges, of 10, 12.5, 25, 50, 100, 160, 200, 400 and 800 amps. capacity. The secondary capacity is 5 amps., adapting it to use with all standard a.c. ammeters, wattmeters and power factor instruments. The volt-ampere rating is



25, and the transformer is compensated for a load of 15 volt-amperes, which high rating is said to enable one transformer to operate several instruments simultaneously at high accuracy. The cast aluminum cases are made for rough usage. After assembly, all moisture is removed from the windings and the case is then completely filled with an insulating compound. This makes the transformer safe to use in mines, manholes and damp places. The weight is 28 lbs. The cores are made of a specially selected grade of electrical sheet steel, proportioned to give exceedingly low ratio and phase angle errors. Each transformer is provided with a built-in secondary short-circuiting switch for the protection of the operator. Finish is black baked enamel and nickel plate.

Cross-hatching Device

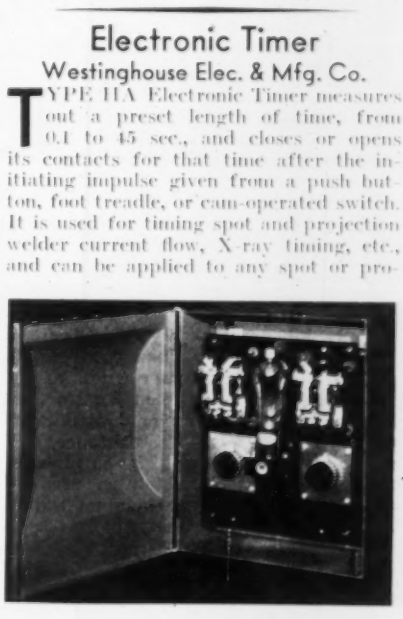
The Nelson Section Liner Co.

FOR use on the drawing board to produce perfect cross hatching, this new instrument, manufactured of laminated Bakelite in opaque red, green, black and golden brown, is for use with the present T-square and triangles, is easily operated and eliminates eye strain.

Electronic Timer

Westinghouse Elec. & Mfg. Co.

TYPE HA Electronic Timer measures out a preset length of time, from 0.1 to 45 sec., and closes or opens its contacts for that time after the initiating impulse given from a push button, foot treadle, or cam-operated switch. It is used for timing spot and projection welder current flow, X-ray timing, etc., and can be applied to any spot or pro-



jection welding machine now in service which is equipped with a magnetic main contactor. This timer is unusually rugged as the industrial grid glow tube operates the contactor directly without delicate intermediate relays. The grid glow tube is free from any effects of wide temperature changes. Timing is variable by means of coarse and fine adjustments. The coarse adjustment consists of a tap switch for changing connections to fixed resistors. The fine adjustment is a wire wound potentiometer. Long timing periods are thus made possible without the use of variable high resistance grid leaks. For applications requiring the highest accuracy, provisions can be made to eliminate entirely the errors inherent in closure of contactors. This is done by the use of an auxiliary contact on the main contactor arranged so that the timing is started from the instant the contactor—not the control switch—closes. The contactor in the unit has a contact capacity of 10 amps. at 115 volts and 5 amps. at 220 volts a.c.

Photoelectrically Balanced Recording Potentiometer

By C. Owen Fairchild*

IN this radically new type of recorder-controller a sensitive mirror-galvanometer is the primary controlling element in which an inertialess beam of light takes the place of the customary metal boom or pointer. The beam of light from the galvanometer to a photocell is interrupted by right and left shutters operated in synchronism with electric contacts in an electromagnetic circuit through which in turn are operated the moving contact of the Wheatstone bridge or potentiometer, and the recording and controlling mechanisms. The photocell is not a calibrated element but serves only to detect the direction of the light beam and bring the galvanometer to zero deflection, according to the well-known null method of balancing an electric circuit. The new instrument, therefore, is *not* a "photoelectric potentiometer" in the sense which implies a balance of photoelectric currents.

It is evident that the galvanometer is free at all times from mechanical engagement. This, and its low moment of inertia, permit rapid balancing and control actions. A high current sensitivity is available, permitting the use of high resistance, or of unusually long thermocouple leads without material loss of accuracy in balancing. Or, on occasion, an unusually low scale range does not require an extremely low resistance and attendant disadvantages. The galvanometer, of course, is completely enclosed. A special feature is its platinum-gold alloy suspension of particularly high tensile strength.

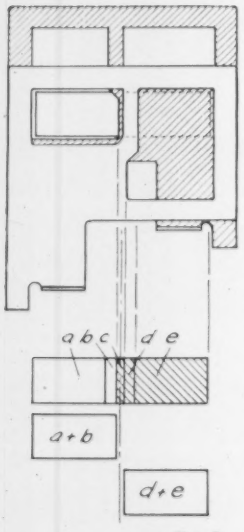


Fig. 1

Balancing Power Circuit. The opening before the photocell is divided by means of right and left shutters of offset outline (Fig. 1) into five effective areas, *a, b, c, d* and *e; c* being the center. These shutters are raised and dropped alternately by two cams, right and left, and these with a third, the power cam, operate three sets of contacts. A relay closes when the light beam from the galvanometer strikes the photocell, and opens when it is cut off by a shutter. Thus, if the light is in area *a*, raising the right shutter will not cut it off but if it is in area *b*, raising this shutter will let it strike the cell, and cut it off when the shutter drops. The right and left contacts are closed while both shutters are down, ready to stop the contact carriage when the light beam swings into area *b, c* or *d*. The power contact is closed only while one or the other of the shutters is closed. At this time only one of the left and right contacts is closed.

Now if the light is in area *a* the contact carriage (and the light beam) start to the right. The conditions for this are (1) relay closed, (2) left contact closed and (3) power contact closed. These conditions are met *only* while the right shutter is up and the light is in *a* or *b*. If it is in *a* the relay does not open when the shutter drops, but if it is in *b* the light is cut off by the drop of the shutter and the relay does open. This results in the conditions (1) relay open, (2) left contact closed and (3) power contact open; and the carriage stops. Thus, when the light is in *b* the carriage takes a short step. When it is in *a* it will not stop because the conditions for stopping it are never fulfilled until it reaches the end of the scale. They are not fulfilled while the *left* shutter is up, because at this time the left contact is open.

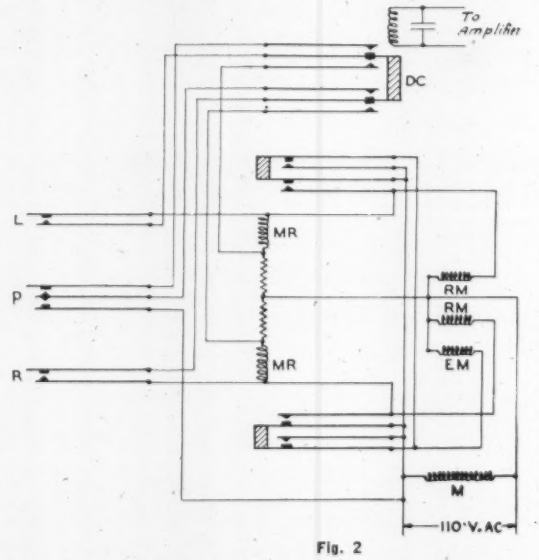


Fig. 2

Finally the light beam swings into area *c* and the relay remains open. In Fig. 1 *c* is shown bounded by two edges of the shutters slightly off the center line. These two edges of the real shutters are coincident on the center line and a virtual area *c* results in this way: When the light beam is at the center, and one shutter rises half the light reaches the photocell, which is insufficient to cause the relay to close, but if the light is slightly off center and more than half the light reaches the cell, the relay may close. The necessary amount off center is half the width of the virtual area *c*.

No adjustment of the timing of the shutters and contacts is necessary or provided for, the cams being mounted on a square shaft. A complete cycle of operations requires 1½ seconds, during which time the tests for the presence of the light-beam in one of the five areas are completed and the proper motion of the carriage controlled.

The complete balancing power-circuit is shown in Fig. 2. The carriage is driven by a special Telechron motor *RM*, the field coils of which are connected to the contacts of two motor relays *MR*. These a.-c. relays are operated by the simultaneous closing of the power contact, one of the left and right contacts and the d.-c. relay repeatedly mentioned as "the relay" in the preceding paragraphs. The motor relays are wired to stay closed until their coils are short circuited. This accounts for the continuous travel of the carriage as long as the light beam is in area *a* or *e*. They both are connected also to the coil of an electromagnetic stop *EM* which is lifted when the motor starts and engages a toothed wheel when the motor is disconnected.

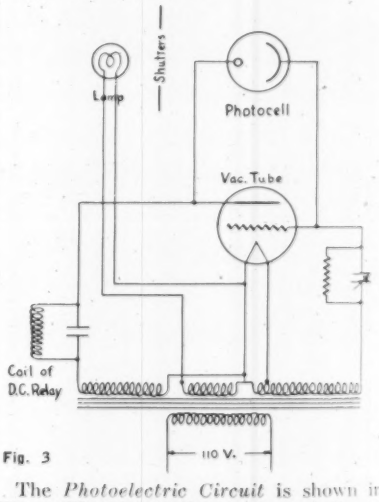


Fig. 3

The *Photoelectric Circuit* is shown in Fig. 3. The photocell is connected directly from plate to grid of the vacuum tube, the grid circuit of which includes a small adjustable condenser shunted by 70 megohms. The plate circuit includes the d.-c. relay coil shunted by a condenser to smooth out the intermittent direct current. The lamp and the tube filaments are directly connected to low voltage sections of the secondary of the transformer. The photocell, of the vacuum type, is operated at low illumination (about 0.1 lumen) so that there is no effect on its life; and the vacuum tube can deliver many times the plate current

*Director of Electrical Research, C. J. Tagliabue Mfg. Co.

used here, 5 or 6 m.a. intermittently, while its 2.5 volt filament is operated at 1.7 volts. They will require replacement less often than the special lamp which is designed to last one year. The adjustable condenser is employed principally as a factory adjustment to care for the characteristics of the tube, cell and lamp, and occasionally by the user to care for widely abnormal line voltage.

The simple *Recording and Commutating Mechanism* requires little description. It merely serves, in a recorder, to turn the multiple switch, depress the stylus wheel mounted on the contact carriage, and occasionally connect the standard cell. The mechanism is locked inactive while the contact carriage is traveling in one step from one recorded temperature to the next, and is released by the opening of the electromagnet *EM*. Fifteen seconds after this a record is made and the switch and stylus wheel turned. During these fifteen seconds, ten or fewer short steps as needed, are taken, to bring the contact accurately to the balance point. Once in every 120 records (30 to 60 minutes) a switch disconnects the thermocouples and connects the standard cell, causing the mechanism to record the standard current. Thus, not only is the condition of the battery apparent at all times, but small corrections can be made without readjustment of the current. The commutating switch with platinum-gold alloy contacts is completely enclosed. These non-corrodible contacts require only a slight wiping action, and reliable electrical connection with each thermocouple is assured without appreciable wear over a period of years.

Records appear as series of colored dots of great visibility, a type of ink being used which dries on the paper in a few seconds and stays on the ink pads for months. The standard instrument is wired for twelve thermocouples with convenient means for connecting fewer.

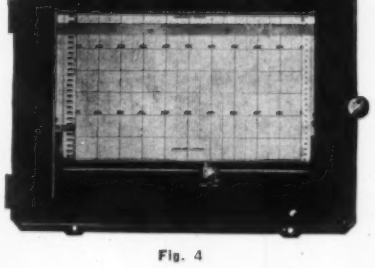


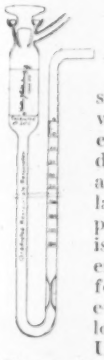
Fig. 4

A cycle of twelve temperatures is ordinarily completed in about five minutes, but for special purposes, with some limitations as to spread of the temperatures, this time can be reduced to 3 and even 2 minutes. Charts are 11" wide with a 10" scale. Standard speed of 1" per hour (sixty days) is readily changed to 2, 3, 4 or 6" per hour. The synchronous drive requires a.c. The chart (see Fig. 4) is in full view and the prominent stylus wheel serves as indicator. The dust- and fume-proof case, which measures 15" × 12" × 12", merely contains the mechanism which, assembled to its own hardened aluminum alloy frame, not only swings out of the case but operates when swung-out—permitting thorough inspection without interrupting service. The terminal board has a compartment to itself, with a separate cover-plate. All power contacts are enclosed. The recorder weighs only 43 lbs. complete.

Re-evacuable Barometer

Podbielniak Industrial Research Labs.

NOT less accurate than a precision type single-tube barometer, this radically novel type is shipped empty and filled at point of use without special equipment and without disturbing adjustments or settings—of which there are not any. In addition, a full range of pressures extending from absolute vacuum to 800 mm. Hg. is etched on the scale leg in 1 mm. divisions. This scale takes into account corrections for irregular bore, capillarity and temperature. Guaranteed accuracy is said to be ±0.15 mm. over entire range when instructions for cleaning, filling and re-evacuating are properly followed. The barometer is of the U-tube form, is constructed of Pyrex glass and has a special head and mercury seal stopcock which permit cleaning and re-evacuating in the field.



Heat Control Switch

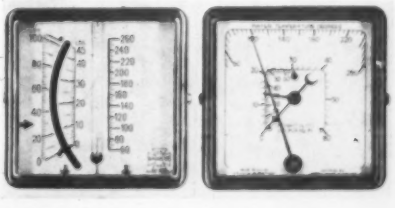
General Electric Co.

FOR use with heating equipment such as oil and gas burners, stokers and unit heaters, this new thermostatically controlled switch comprises a relay and a small 2-winding transformer mounted in a pressed-steel enclosure. The transformer furnishes approx. 20 volts for use across the contacts of a controlling thermostat, which low voltage permits the device to be used in conjunction with a close-differential thermostat. The relay itself—a new development suitable for use as a separate device in control equipment—can carry 10 amps. continuously and can be used to control a ¼-h.p. motor at 110 or 220 volts.

Square Case Pressure and Combination Gages

United States Gauge Co.

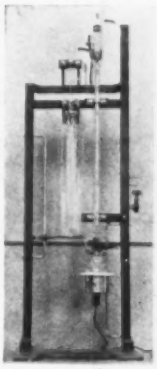
MODERN design ideas are embodied in the new cases in which the makers are prepared to supply their various types of pressure and combination gages. Any one combination can be produced, *i.e.*, combination bimetal thermometer and pressure and altitude gage, or combination glass tube thermometer and pressure and altitude gage, or steam pressure gage with or without internal siphon, or compound pressure and vacuum gage with or without retard features. All of these may be furnished bottom or back connected as required. The new design makes an attractive installation on boilers having rectangular jackets and the 3½" size has been adopted by manufacturers of house heating boilers. Gages may also be supplied with suitable adjustable flanges for concealed mounting.



Distillation Apparatus

Podbielniak Industrial Research Labs.

COMPOUNDS with boiling points <500°C. can be fractionated with this new apparatus, the design of which is based on the use of a vacuum jacket form of insulation and of a wire coil packing. Distillations can be conducted at atmospheric pressure or at pressures as low as 2 mm. Hg. abs. It is said that extraordinary sharpness of separation is obtained by reason of the design features mentioned and of the careful construction. This new apparatus is designated as the "Model E High Temperature Fractionating Apparatus."



"Ther-alti-meter"

Jas. P. Marsh Corp.

PROVIDING a means for convenient reading on the one instrument of hot water or low steam temperatures as well as pressures or feet of water, this new instrument is applicable for use on hot water house heating boilers, on steam apparatus where steam pressure and temperature are to be shown, on piping, etc. In standard construction it is made up with dial reading from 80 to 250°F., and from 0 to 30 lbs. pressure and with altitude reading from 0 to 70 ft. of water. Over-pressure protection is provided. The instrument is made up in 3½" dial size, drawn case and ring, black all-over finish or colors to match apparatus, also with nickel plated, chrome plated or polished brass finish. Standard with ½" I.P.S., either bottom connected or lower back connection. As is evident from Fig. 1, there are two separate and independent mechanisms—one for temperatures and the other for pressure or altitude. Both are of the Bourdon tube type.

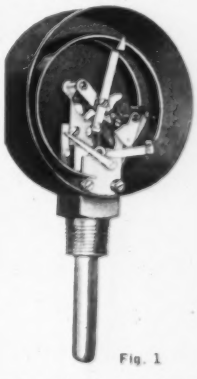


Fig. 1

Fig. 2

Control Relay Sets

Signal Engineering & Mfg. Co.

FOR two-wire control, these new instrument controlled relay sets consist of the relay itself, a condenser and an external resistor. For three-wire control (H, C and L) the sets consist of the relay and an external resistor, as shown in Fig. 1, which, however, does

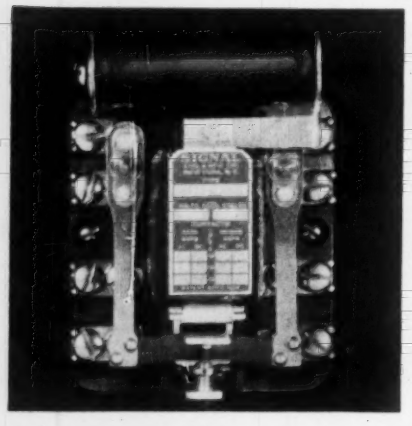


Fig. 1

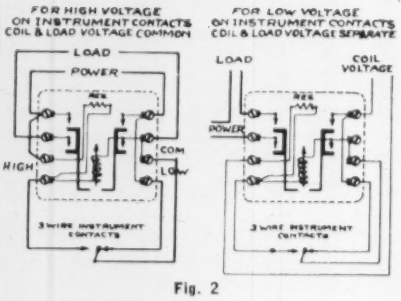


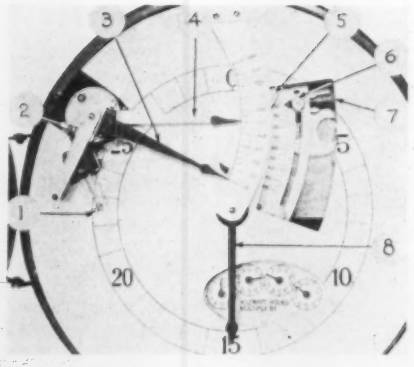
Fig. 2

not show the housing. Two styles of housing, stamped steel and weatherproof, are available. The advantage is said to be that balanced sets for use with contact-making instruments are at last available, all elements comprising each individual set having been matched to minimize current required for operation. Contact ratings up to 30 amps. a.c. or 20 amps. d.c. are available. Momentary loads on instrument contacts, by virtue of proper balance, are from 0.008 to 0.18 amp.—this maximum being that for 30 amps. in load circuit. These sets have primarily been designed to operate from contact-making galvanometers, gages, thermal instruments, etc.

Quick-signal Demand Meters

General Electric Co.

THE use of demand meters to assist in keeping the maximum demand at the lowest practical level loses much of its advantage when the signal or warning is given after the predetermined maximum demand has been reached. These new demand meters, it is said, successfully avoid this limitation by having a set of alarm contacts so arranged that they will close if, for any elapsed part of the time interval, the "demand" (number of impulses to the demand meter) exceeds the predetermined value for that part of the time interval. In order to obtain this operation, the contacts must be actuated jointly by two



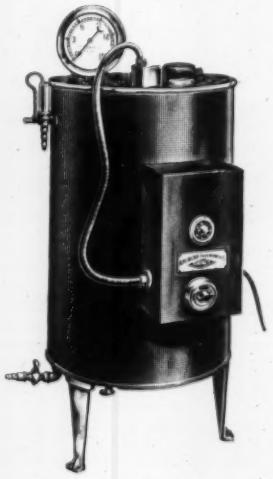
1. Alarm contacts
2. Adjustment for alarm contacts
3. Actual-demand pointer
4. Ideal-demand pointer
5. Time-interval disk
6. Adjustable setting "A" for predetermined maximum demand
7. Adjustable setting "B" for establishing starting position of ideal-demand pointer
8. Time-interval pointer

separate members as follows: One member (the ideal-demand pointer) is advanced at a predetermined but adjustable rate for the entire time interval, thereby giving a predetermined value of "demand" for any elapsed part of the time interval. The other member (the actual-demand pointer) is advanced step-by-step to show actual demand. It is actuated by impulses received through a contact device in the watthour meter with which the demand meter is associated. Both members reset to their respective starting positions at the end of the time interval.

Reid Bomb Bath

American Instrument Co., Inc.

IN order to measure the vapor pressure of gasoline correctly by the Reid Bomb Method (A.S.T.M. D323-32T), the bomb must be held at a constant temperature of 100°F. ±0.5°F., in a water bath. Developed expressly for that purpose, this new bath is designed to

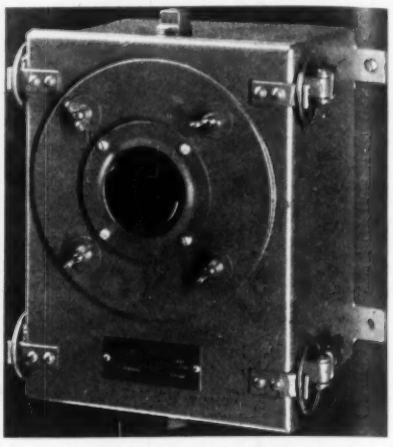


hold four Reid bombs, immersed up to their gages, at the specified temperature. A compact box on the side of the bath houses the control assembly (relay, switch, pilot light, etc.), and temperature is said to be held well within the specified limits by a "Quickset" bimetallic regulator and a "Lolag" immersion heater. The whole assembly works directly from the house current. No batteries or auxiliary connections are required.

Light Source for Photocell Applications

Westinghouse Elec. & Mfg. Co.

TYPE E Light Source for use with light-sensitive equipment is said to be specially useful where transmission of the light beam over a considerable distance is required, or where the light



beam must penetrate steam, dust, etc., as in steel mills, and still retain enough intensity to operate the light-sensitive control reliably. An intensity of 24 foot-candles is obtained at 25 ft. (The intensity varies inversely as the square of the distance.) The Type E Light Source has an industrial lamp rated at 6 volts, 5 amps. and 3000 hours life. Provisions are included for adjusting the focus of the lens with respect to the lamp so as to locate the beam at the desired spot without removing the cover. A transformer makes the lamp operable from any commercial source of power except d.c. The steel cabinet is suitable for either indoor or outdoor mounting. An infra-red filter to provide an invisible radiation beam is an optional accessory.

Glass Transmission Spectrum Analyzer and Recorder

The Pyrometer Instrument Co.

TRANSMISSION characteristics of different welding glasses, filters, etc., in the ultra-violet and infra-red can be determined with ease, it is said, and chart records obtained, by means of the new "Pyro" Super-sensitive Radiation Tube, used in connection with the Pyro Rapid Recorder (*Instruments*, Nov. 1931, page 627). The new tube enables manufacturers and users of absorption glasses, etc., to make tests over a wide range of wave-lengths in a minimum of time. An indicating instrument is optionally available in lieu of the Rapid Recorder.

Electric Erasing Machine

Charles Bruning Co., Inc.

A NEW electric erasing machine, combining lightness and compactness, is designed to be held in the fingers like a pencil, rather than in the fist, and thus enables the operator to maintain accurate finger control. The machine is driven by a self-contained electric motor operating on both 110 a.c. and 110 d.c. A complete assortment of pen and pencil erasers is furnished.

Spring-loaded Testing Machines

Baldwin-Southwark Corp.

ALTHOUGH the idea of the use of a helical spring as a load weighing means had been applied to small testing machines, such use on larger equipment had to wait on developments in metallurgy. Recent advances have made possible sensitive and accurate testing machines using springs for the load reactors. The Southwark Heydekampf Testing Machine, announced in sizes up to 200,000 lbs. capacity, utilizes a ground and lapped ram in a cylinder for load production and for strain compensation (Fig. 1). Fluid under pressure is supplied by a motor-driven pump through appropriate control valves and automatic by-pass mechanisms. The load cylinder is mounted above the working space so that the compression testing space is above the tension. The cross-head above the cylinder contacts a large steel ball between itself and the ram for preventing binding of ram on cylinder walls in the event of an off-center load. In the larger machines the cross-head between the tension and compression spaces is adjustable and is usually motor-operated.

The weighing and indicating system consists of an auxiliary ram (of much smaller diameter than that of the main load ram) in a ground and lapped cylindrical sleeve which is made to rotate continuously while testing is being done, a cross-head attached to two Chatillon Springs, and mechanisms to convert the linear motion of the cross-head into rotary motion of the spindle carrying the indicating hand before the 20" diameter dial face. The auxiliary cylinder communicates by a large pipe with the main load cylinder. This connection is not made to the pipe supplying the fluid under pressure to the main load cylinder, but into the cylinder proper. This construction is such that no pump pulsations may be detected in the action of the indicating hand.

What is said to be a unique feature of this type of testing machine is the use of specially designed and constructed springs, each consisting of two springs in tandem, one having a left-hand and the other a right-hand helix. It is said that they have a negligible temperature coefficient, so that temperature variations between 0° and 120° F. have no appreciable effect on accuracy or on sensitivity; and that having negligible hysteresis, creep and time-strain effects, they present strictly straight line characteristics in the working range.

The new machine is usually built with five ranges obtained with three sets of springs. Thus, a 50,000-lb. machine may have in addition a 25,000-lb., a 10,000-lb., a 5,000-lb. and a 2,000-lb. full-scale range. An arrow indicates at any time (1) the load per division, (2) the range and (3) the serial numbers of the springs in use. A recorder is usually built in. The rotation of the recorder drum is proportional to load, the drum being actuated by the cross-head of the weighing system.

Accuracy: Manufacturer reports that a recent calibration with Morehouse proving rings showed an average deviation of 0.16% in 17 readings in 5 ranges, with a maximum single deviation of 0.45% above 6% full capacity of the machine.

A modification of this type is the 30-lb. testing machine, Fig. 2. The dial gage is double faced and three complete rotations of the indicating hand on its axis are necessary to secure the full 30-lb. The dials are graduated in ounces and are readable to 4 drams (by careful reading, to 2 drams). Loads are applied by hand and either tension or compression tests are possible.

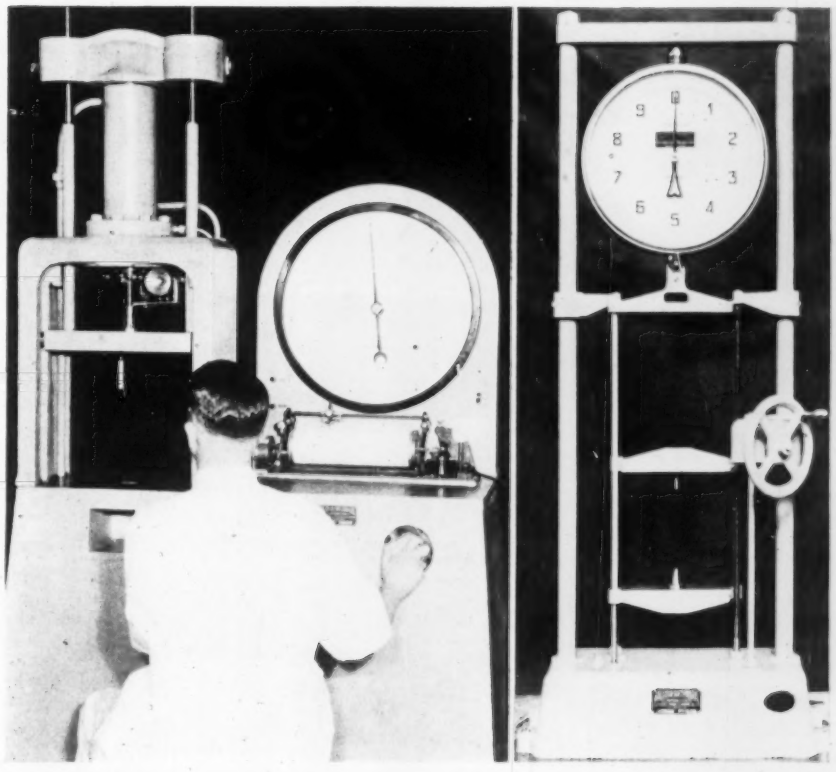


Fig. 1

Fig. 2

DISCUSSION OF BEITLER'S ORIFICE COEFFICIENTS ARTICLE— (Continued from Page 44)

bers used in the article were the values at the outlet face of the orifice, which are the values most commonly used in this country.

In calculating the values of the Reynolds numbers (R_d) used in getting Fig. 5, the familiar formula $R_d = Vd\rho/\mu$ was used in which

V = velocity in ft./sec.
d = orifice diameter in ft.
ρ = density of fluid at outlet plane of orifice, lb./ft.^{3}
μ = absolute viscosity, lb./sec. ft.

Substituting for V values calculated, using the formula

$$V = \frac{C}{\sqrt{1 - r^4}} \times \sqrt{2gh}$$

and putting in the proper constants, this formula becomes for any compressible fluid

$$R_d = 0.914 \frac{F_a\, d_{in}\, \sqrt{h_w \rho}}{\mu}$$

assuming that the coefficient of the orifice C is 0.60, that the value of g is 32.2 and that water has a density of 62.37 lb./ft.^{3} In this formula

F_a = factor for velocity of approach $= 1/\sqrt{1 - r^4}$

where r = ratio $\frac{\text{orifice diameter}}{\text{upstream pipe diam.}}$

d_{in} = orifice diameter in inches
h_w = differential pressure in inches of water

For air at 60° F. this formula can be further reduced to

$$R_d = 5450\, F_a\, d_{in} \sqrt{h_w P}$$

where P = abs. pressure, lbs./in.^{2}

using the values of "R" the gas constant for air as 53.3 and $\mu = .000001209$.

If we assume that the pressure at the downstream plane of the orifice is the upstream pressure less one-half the differential (which is only an approximation) this reduces to

$$R_d = 143{,}300\, d_{in}\, F_a$$

For a 1½" orifice

$$R_d = 215{,}000\, F_a$$

In a 14" line, R_d then equals 215,000 for $F_a = 1.0001$ while in a 2" line where $r = .75$, $F_a = 1.210$ and R_d would be equal to 260,000.

In deriving this formula two assumptions have been made. One is that the coefficient of discharge is 0.6 and the other that the pressure at the orifice section is equal to the average of the upstream and downstream pressures.

The maximum error in R_d from the first assumption is + 2 or −1% from Fig. 5, and if the pressure at the orifice plane was assumed to be the same as the pressure at the upstream or downstream pressure connection, the maximum error due to the second assumption would be only ±3%, so that the total error

possible would be ±4% on the value of R_d. This small difference in the value of R_d will show practically no change in coefficient so that the values of coefficient found using the values of R_d calculated from the above formula should be as accurate as the curves.

The statement "corrected for compressibility" then meant that the coefficients for Fig. 5 are those for air at the given conditions, assuming that there is no correction for compressibility, and a compressibility factor would have to be used to get actual coefficients for air under the given conditions.

The two lower figures on the abscissæ scale in Fig. 5 are the correct ones and the rest should be changed to correspond.

Fig. 6 was determined in the same manner as Fig. 5, using the same values of R_d. It was put in the article to show the close agreement with Witte's values and not primarily as a coefficient curve. However, it can be used in a similar manner to Fig. 5.

The values for coefficient of air at the given conditions were used because they gave about the average coefficient values over the range ordinarily used and the corrections for change in Reynolds number would be either plus or minus. It is much more difficult to set up any similar standard for water, as most water meters operate at a point in the coefficient-R_d curves where the coefficient is varying more rapidly with a change in R_d. For this reason nothing has been done on setting up a liquid standard curve. A curve for water at about the same differential would be approximately ¾ of 1% higher than the corresponding curve for air.

I hope that the above discussion will clarify some of the points raised by Mr. Dawley and assist others who may want to use the values taken from the paper.

The Ohio State University — S. R. Beitler
Columbus, Ohio, Feb. 15, 1934 — *Asst. Prof. Mech. Engg.*

Final Comments

To the Editor:

Thank you for letting me see Prof. Beitler's answer in advance of publication. Now here is my answer to your question:

The main reason why my Reynolds number differed from his was that I used the value of viscosity for air at one atmosphere which is given in paragraph 106 of the latest (Third) edition of Part 1 of the A.S.M.E. Fluid Meter Committee's Report—an authoritative work which we all use as a standard source and which Prof. Beitler cites again and again. The value as given there is 0.0000178 in English units, whereas Prof. Beitler—it now appears from his letter—used the value of 0.0000209. I presume he is right, because I note that the values in par. 106 do not check with Table 2 in par. 109.

I am glad I raised these questions, because if engineers in general are to make use of Reynolds numbers they will have to know how to figure these numbers correctly. Data on absolute viscosity are not readily available and certainly the A.S.M.E. report ought to be a reliable source.

I think the Reynolds number for the water coefficients (Fig. 4 of Beitler's article) should be figured out; and a sample calculation should be given, so that anyone trying to use these curves would have a guide for checking on his own calculations of the number.

It seems to me, on the whole, that the air curves should be used with caution, as they are based on tests with water and on the assumption that the air coefficient is the same for the same Reynolds number.

New Jersey Meter Co. — C. A. Dawley
Plainfield, N. J., Feb. 19, 1934 — *Chief Engineer*

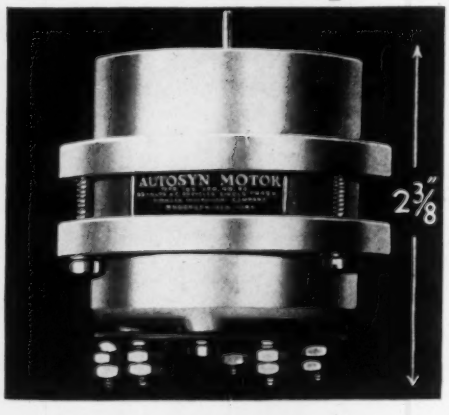
Mea Culpa

Whatever points in Professor Beitler's article needed elucidation are now clarified by this discussion.

Professor Beitler generously refrains from mentioning that it was your editor who requested him "to present as many facts as possible in a minimum of words." This is not our usual policy but his important graphs *did* require lots of space in order to be easily readable (hence accurately usable) and so, his original manuscript *did* look somewhat bulky in relation to the space left.

One last point: Professor Beitler's caption under Fig. 5 should be understood to mean that the *Reynolds number* has been corrected for an air density corresponding to a pressure of 30" of mercury minus 25" of water. It should not be understood to mean that the *coefficient* has been corrected for the change in density of the air.—M.F.B.

autosyn



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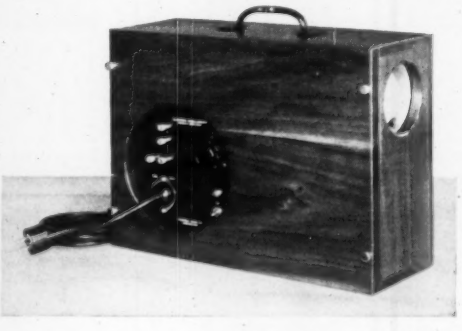

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